

NAVAL POSTGRADUATE SCHOOL

Monterey, California



THESIS

**THE MOBILE AIRCRAFT MAINTENANCE OFFICE
CONCEPT FROM A WIDE AREA PERSPECTIVE**

by

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March 2003

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WIDE AREA PERSPECTIVE**

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requirements for the degree of

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ABSTRACT

As mobile computing becomes more ubiquitous, through the use of very capable mobile computing devices and broadband wide area wireless data networks, naval aviation maintenance has an opportunity to extend the reach of the Naval Aviation Logistics Command Management Information System (NALCOMIS) to fielded aircrew, maintenance technicians, and maintenance supervisors supporting out of local area operations. The combination of the new mobile technologies and the wireless Internet makes modern Mobile Business (m-business) initiatives possible but ushers in a host of new problems and issues that are radically different from those experienced with traditional fixed electronic business (e-business) projects. This thesis examines the concept and components that comprise m-business, details wide area data over cellular technologies, and identifies problems and issues unique to m-business initiatives. Scenario-based Use Cases will be employed within the Unified Process (UP) framework to develop the three major artifacts of the UP's inception phase - the project's vision, a Use Case model, and a supplemental specification containing functional and non-functional requirements for an aircrew mobile aircraft maintenance application. The results of this study can serve as the foundation for the development of a complete mobile aircraft maintenance office.

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LIST OF ACRONYMS

1G	First Generation Cellular Network Systems
1X	One Times Radio Transmission Technology
1xEV-DO	One Times Evolution- Data Only
1xEV-DV	One Times Evolution- Data and Voice
1xRTT	One Times Radio Transmission Technology
2.5G	Two Point Five Generation Cellular Network
2G	Second Generation Cellular Network Systems
3G	Third Generation Cellular Network Systems
3GPP	Third Generation Partnership Program
3GPP2	Third Generation Partnership Program 2
3X	Three Times Radio Transmission Technology
3xRTT	Three Times Radio Transmission Technology
8-PSK	Eight Phase Shift Keying
AAA	Authentication, Authorization and Accounting Server
ADB	Aircraft Discrepancy Book
AIA	Aircraft Inspection and Acceptance Record
AMPS	Advance Mobile Phone Service
AMR	Adaptive Multirate
APU	Auxiliary Power Unit
B2B	Business to Business
B2E	Business to Employee
BoD	Bandwidth on Demand
BPSK	Binary Phase Shift Keying
BSC	Base Station Controller
BTS	Base Transceiver Station
CDMA	Code Division Multiple Access
CDMA2000	Code Division Multiple Access 2000
CDPD	Cellular Digital Packet Data
CF	Compact Flash
COA	Care of Address
CPCH	Common Packet Channel
CS-2	Coding Scheme 2
D-AMPS	Digital Advanced Mobile Phone Service
DHCP	Dynamic Host Configuration Protocol
DoD	Department of Defense
DSSS	Direct Sequence Spread Spectrum

DTPL	Dispersed Technical Publication Library
EBP	Elementary Business Process
E-BUSINESS	Electronic Business
E-COMMERCE	Electronic Commerce
EDGE	Enhanced Data Rates for Global Evolution
EIC	Electronic Identification Code
FACH	Forward Access Channel
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
F-FCH	Forward Fundamental Channel
FM	Frequency Modulation
FOMA	Freedom of Mobile Access
F-SCH	Forward Supplemental Code Channel
FURPS	Functional, Usability, Reliability, Performance and Supportability Requirements
GGSN	Gateway GPRS Serving Node
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
GSMK	Gaussian Minimum Shift Keying
GSN	GPRS Serving Node
GTP	GPRS Tunneling Protocol
HA	Home Agent
HDML	Handheld Device Markup Language
HDR	High Data Rate
HLR	Home Location Register
HPSK	Hybrid Phase Shift Keying
HTML	Hyper Text Markup Language
IETM	Interactive Electronic Technical Manuals
IMT	International Mobile Telecommunications
IMT-2000	International Mobile Telecommunications-2000
IP	Internet Protocol
ISDN	Integrated Services Digital Network
ISIC	Immediate Superior in the Chain of Command
ITU	International Telecommunications Union
LAN	Local Area Network
M-BUSINESS	Mobile Business
MC	Multiple Carrier
M-COMMERCE	Mobile Commerce

Mcps	Mega Chips Per Second
MRC	Maintenance Requirement Card
MSC	Mobile Switching Center
MSEC	milliseconds
MSS	Mobile Satellite Service
MTS	Mobile Terminal Set
NALCOMIS	Naval Air Logistics Command Management Information System
NAVFLIR	Naval Flight Report Subsystem
NMT	Nordic Mobile Telephony
NTCSS	Naval Tactical Command Support Information System
NXI	Navy XML Infrastructure
PC	Personal Computer
PCS	Personal Communications System
PDA	Personal Digital Assistant
PDC	Personal Digital Cellular
PDSN	Packet Data Serving Node
PN	Psuedonoise
PPP	Point to Point Protocol
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Modulation Phase Shift Keying
RACH	Random Access Channel
RAN	Radio Access Network
RC	Radio Configuration
R-FCH	Reverse Fundamental Channel
RN	Radio Network
RNC	Radio Network Controller
R-SCH	Reverse Supplemental Code Channel
SGSN	Serving GPRS Service Node
SIP	Session Initiation Protocol
SMS	Short Message Service
SR	Spreading Rate
TACS	Total Access Communications Systems
TCP	Transport Control Protocol
TD-CDMA	Time Division Code Division Multiple Access
TDD	Time Division Duplex
TDMA	Time Division Multiple Access

UC	Use Case
UE	User Equipment
UML	Unified Modeling Language
UMTS	Universal Mobile Telecommunications System
UP	Unified Process
URPS	Usability, Reliability, Performance and Supportability Requirements
USEC	Micro seconds
UTRAN	UMTS Terrestrial Radio Access Network
VLR	Visitor Location Register
VoIP	Voice over Internet Protocol
VPN	Virtual Private Network
WAP	Wireless Application Protocol
W-CDMA	Wideband Code Division Multiple Access
WEN	Web Enabled Navy
WEP	Wired Equivalent Privacy
WLAN	Wireless Local Area Network
WML	Wireless Markup Language
WWAN	Wireless Wide Area Network
XLST	XML/eXtensible Style Language Transformation
XML	eXtensible Markup Language

I. INTRODUCTION

A. BACKGROUND

Today's automated naval aircraft maintenance environment consists of a wired client/server based maintenance management information system, central databases, and electronic technical publications, which have replaced or supplement legacy paper-based systems. These computer-based initiatives have added great value and have significantly streamlined aircraft maintenance, status reporting, and logistics processes. One of the key capabilities of these systems is their ability to provide near real time aircraft maintenance information and status to users, managers, and decision makers from a central database. Since the majority of the maintenance and flight transactions take place at the unit's home shore or shipboard location, the aircraft maintenance information infrastructure is optimized for local wired network operations.

Organizational level aviation aircraft maintenance relies on the Naval Air Logistics Command Management Information System (NALCOMIS) program for collecting and storing aircraft and engine configuration data, aircraft discrepancies (e.g., Aircraft Discrepancy Book (ADB)), and aircraft log book records. Additionally, it is possible for technicians to access Interactive Electronic Technical Manuals (IETM) through NALCOMIS making the entire aircraft specific Dispersed Technical Publications Library (DTPL) available via a mobile device such as a laptop computer. Furthermore, aircrews interact with NALCOMIS to document discrepancies, review outstanding and completed maintenance actions via the automated ADB, check aircraft mission configuration, and document post mission aircraft flight data. This system is the aircraft management information backbone providing squadron maintenance managers, technicians, and aircrew with critical information on maintenance activities and aircraft status while automatically keeping superiors and the logistic chain of commands informed. This capability significantly improves command and control and logistical response times.

The convenience of centrally storing these powerful programs, databases, and resources within wired private network infrastructure has its drawbacks when

maintenance and flight transactions occur at remote airfields resulting from a precautionary landing or multi-leg cross-country flight. In these situations, the field maintenance team or aircrews do not have access to the aforementioned resources of the squadron's internal network nor do they have an effective way to access required technical support normally available at the parent organization. These drawbacks significantly degrade the near real time information sharing features of NALCOMIS and introduce significant inefficiencies and barriers to effective remote aircraft maintenance.

A potential solution to this problem is the development of a Mobile Aircraft Maintenance Office Concept utilizing mobile devices, suitable middleware, and wireless cellular technologies. The ultimate goal is to give fielded maintenance and aircrew personnel the same tools and assets available within the boundaries of the parent organization. This type of mobile connectivity extends NALCOMIS' near real time aircraft status and logistics information sharing capability from the parent organization to the fielded users and vice versa.

B. THE NEED FOR A MOBILE MAINTENANCE OFFICE

During squadron training cycles and deployment operations, multi-leg cross-country flights and remote site maintenance are very common. When an aircraft is located away from its parent organization's facilities, mobile maintenance teams and aircrew either carry a standalone laptop to capture NALCOMIS data or revert back to the manual paper-based system to document maintenance actions and flight data. In either situation, there is no extranet¹ connection with the parent command to synchronize the NALCOMIS information between the standalone laptop or paper-based system and the central server. This process not only degrades the information sharing capability, it also introduces inefficiencies and barriers to effective maintenance. Additionally, this process effectively negates the system's capability to keep the Immediate Superior In the Chain

¹ Extranet is defined as a network system that extends an organization's intranet to include specific authorized entities outside the boundaries of the organization, such as fielded maintenance technicians and aircrews.

of Command (ISIC)² and logistic support properly appraised, thus reducing their ability to respond to the situation. Furthermore, the mobile field team is cut off from technical directives, conditional inspections, important maintenance tasking, and technical publication changes that may have been issued since their departure and must be communicated via phone conversation or messenger. Lastly, technicians in the field do not have access to the knowledge and expertise provided by technical representatives, who are normally available at the parent organization, except by phone. There is currently no field capability to videoconference or capture and pass digital imagery to the knowledge base residing back at the parent command. Dispatching technical expert support to perform “on-site” aircraft damage assessment is expensive and is often not necessary which results in wasted man-hours and repair delays.

When an aircraft makes a planned or a precautionary landing at a remote location, defined as an airport or landing site other than the home base airfield, aircrews have no effective mechanism to interact with the NALCOMIS system. This inability imposes barriers to efficient ADB reviews, daily and turnaround inspections documentation, and completed flight data inputs. Additionally, aircrews are cut off from post departure maintenance or inspections requirements mentioned above, thus creating a potential safety of flight situation. Furthermore, when the landing is a result of malfunction, aircrews have no way to capture and transmit visual data (e.g., digital pictures or video conference) of the damaged component to the parent organization. This inability often leads to an incorrect diagnosis as to the severity of the problem, sub-optimal field maintenance team composition, unnecessary repair part requisitions, and the failure to efficiently identify required tools or repair kits to correct the discrepancy.

In summary, naval aviation as a whole is a mobile business that requires fielded maintenance and aircrew users to have access to the unit’s maintenance management information systems and technical resources when detached from home base. M-business concepts incorporating today’s powerful mobile computing devices, advances in wireless

² Immediate Superior In the Chain of Command (ISIC) is the decision maker with the direct oversight of training, maintenance, and readiness of assigned assets. In the context of this discussion, the term ISIC implies squadron level decision makers.

cellular technologies, and effective and flexible m-business cross platform applications³ may provide a viable solution to the short comings of the current aircraft maintenance management information system. A mobile aircraft maintenance office solution may facilitate a field user's ability to carry out his or her mission. In addition, it keeps the system's near "real time" capability intact and ensures that superiors and logistics commands are able to orient, observe, decide, and respond in the manner originally envisioned by the NALCOMIS initiative, regardless of the aircraft's physical location.

C. PURPOSE AND SCOPE OF RESEARCH

The intent of this research is to explore the feasibility of implementing a mobile aircraft maintenance office pilot program and how to best leverage advances in wireless cellular technology as part of a solution. In order to succeed at this task, one must first define m-business and understand the unique problems specific to mobile applications when compared to traditional wired systems. To determine the project's feasibility and derive the functional requirements, which define the system's hardware, software, and middleware⁴ characteristics, it is important to employ a modern, user centric, design approach. Additionally, an in-depth study of current and evolving cellular wireless network technologies will aid in determining whether they add value as part of mobile maintenance office solution. Specific research questions the author sets out to answer are:

1. What is m-business? To implement a mobile aircraft maintenance office solution using wireless networks, what key m-business infrastructure issues need to be identified and addressed?
2. What network platforms define cellular technologies? How does Third Generation (3G) cellular technology differ from traditional cellular technologies employed today? Is 3G a global standard? If not, which standard will be most prevalent in the United States and overseas?
3. What are the basic functional and supplemental requirements for mobile aircraft maintenance application? How do the users interact with the system and what is the system expected to do?

³ Cross platform applications are defined as applications that are capable of supporting different mobile platforms such as laptops, Personal Digital Assistants (PDA), and smart phones over different network environments.

⁴ Middleware is defined as software that connects two otherwise separate applications.

4. Is there a mobile computing model that is best suited for the mobile aircraft maintenance application? Will wireless cellular networks sufficiently support the requirements of the mobile maintenance office application?
5. Is the mobile aircraft maintenance office concept feasible and does it add value to the naval aviation maintenance information management system?

D. ASSUMPTIONS

There are certain assumptions the author made in writing this thesis. Specifically, that NALCOMIS and other automated maintenance management information systems will remain as a part of the Chief of Naval Operation's Web Enabled Navy (WEN) initiative. Another key assumption is that the cellular network operators will deploy nationwide 3G systems as they are envisioned today. Though there is an extensive review of key concepts provided in this thesis, it is assumed the reader has a basic understanding of networks, the associated functionality of their components, and the Internet Protocol (IP).

E. THESIS ORGANIZATION

The thesis is organized into four chapters and three appendices. Chapters I and II provide an introduction to the key concepts and issues regarding m-business and the required infrastructure functionality that make it feasible. Chapter III concentrates on determining an effective development approach and deriving functional and non-functional system requirements using the Unified Process (UP) and scenario-driven Use Cases. Chapter IV summarizes the conclusions derived from the research and recommends areas for further research. A detailed survey of the evolution of cellular technologies, a review of the 3G specification, the issues surrounding its implementation, and an in-depth technical discussion of the two most predominant 3G system architectures, data capabilities, and required protocols is presented in the three appendices and are referenced throughout this thesis.

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II. MOBILE BUSINESS APPLICATION

A. INTRODUCTION

Naval aviation maintenance has evolved from a paper-based system to a PC centric system over the last decade. NALCOMIS began as a UNIX based, client-server system that primarily focused on automating the existing maintenance, flight data and supply chain process. In the beginning of 2000, the system's evolution continued emphasizing aircraft maintenance process reengineering and the implementation of the Windows NT based, NALCOMIS Optimized program. As of this writing NALCOMIS, as part of the Naval Tactical Command Support information System (NTCSS), is identified as one of the information systems slated for conversion from an application specific system to a browser based, web enabled system as part of the Navy's Web Enabled Navy (WEN) initiative. The WEN electronic business⁵ (e-business) initiative combined with the increasing mobile device computing power, significant improvements in wireless network data rates, and enhanced mobile application platforms offers an opportunity to effectively integrate m-business applications into the next generation NALCOMIS.

The Navy's Task Force Web, as chartered by the WEN initiative, is developing a strategy to take advantage of web technologies in order to create integrated and transformational information exchanges. The ultimate goal of this effort is to deliver the user a personal view, via a single portal, of Navy business and operational systems, and promote interoperability between Navy enterprises using the Navy eXtensible Mark up Language (XML) Infrastructure (NXI) interface (Task Force Web, 2001). Figure 1 captures the essence of the envisioned WEN architecture.

⁵ E-business is defined as Business to Business (B2B) and Business to Employee (B2E) activities conducted using electronic data transmission over the Internet and World Wide Web and usually designed to interface with existing back office systems.

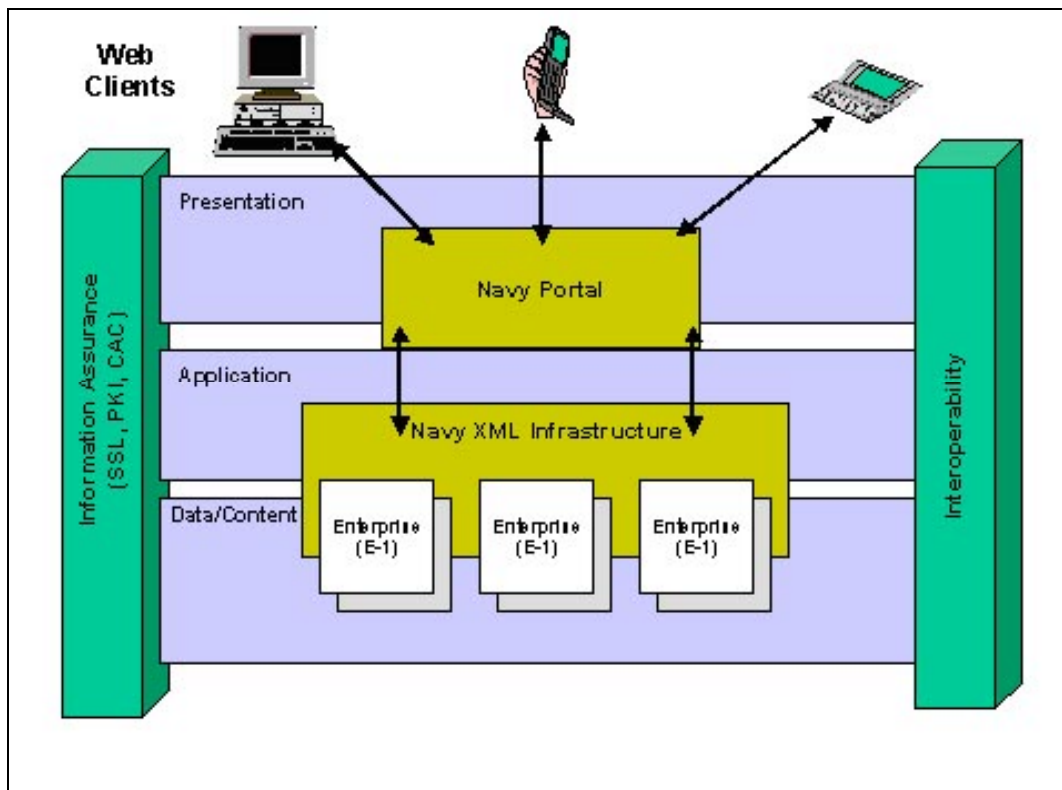


Figure 1. Three Tiers of the Web Enabled Navy.
(From: Task Force Web, (2001), p. iv)

This e-business initiative lays a solid foundation for integrating mobile business into the envisioned framework. However, it is important to realize that e-business initiatives employing web technologies do not automatically translate into effective wireless m-business applications. Mobile business applications and infrastructure have to account for the unique characteristics of the wireless network environment, the multitude of different device profiles, and the limited computing, memory, and battery capacity of mobile computing devices. Electronic business applications designed specifically for the wired web do not have to account for these types of variables.

As mentioned above, NALCOMIS will be transformed from a stove piped wired network application into that of a web enabled e-business system. This transition is the next evolutionary step in the automated maintenance environment, but fails to identify maintenance applications that can enhance the new systems capability by implementing

both mobile and wireless technology. Aircrew and maintenance personnel routinely conduct operations and maintenance away from their parent command housing NALCOMIS, making mobility⁶ and wireless access to portions of the system a valid requirement.

Prior to the automation of the aircraft maintenance management process, the maintenance, flight data, and supply processes of the parent command matched that of fielded teams and aircrew. Whether home or away, aircrew and maintenance personnel used the same, paper-based system utilizing maintenance action forms, aircraft release sheets, Naval Flight Reporting Subsystem (NAVFLIRS) and replacement part request forms to capture aviation data. With the introduction of NALCOMIS, parent command processes benefited from a client-server PC centric system that streamlined aircraft, flight, and supply management. The system captured information and made it available to personnel, with proper authority to access the system, from any PC connected to the network. However, when detached from the parent command, personnel use stand-alone NALCOMIS laptop computers or paper-based procedures to display or capture aircraft maintenance, flight, and supply management data. This ad hoc process results in a breakdown in information sharing between maintenance managers at the parent command and the fielded personnel. The accepted method for synchronization of data between the two entities during field maintenance or during cross-country flights is via phone or naval message. Upon return, information is either uploaded or re-entered into the parent command's NALCOMIS database. This process effectively negates the intended efficiencies and effectiveness envisioned by the original creators of NALCOMIS and results in wasted man-hours, decreased supply chain efficiency, and increased aircraft down time.

Optimized for the wired Internet environment, the next generation NALCOMIS will not likely be suitable for the wireless mobile environment. To avoid this shortfall, it is imperative, that the next generation NALCOMIS architecture address m-business' concepts, issues, and constraints from its inception. Specifically, the new NALCOMIS

⁶ Mobility is defined as a portable platform capable of both online, near real time Internet transactions, and offline operations that can be later synchronized to the central system.

development process must identify aircraft maintenance management applications that are well suited and can add greater value through wireless m-business applications. These initial applications will form the necessary foundation in the core architecture to facilitate a more cost effective and integrated approach and enhance the system's overall effectiveness.

Business experts see m-business as the next evolutionary development after e-business. Naval aviation maintenance decision makers must understand the mobile wireless landscape and explore the requisite m-business concepts, architectures, and integration issues necessary for successful implementations. There is a strong business case for a mobile aircraft maintenance capability and it is long overdue. The WEN initiative combined with the next generation NALCOMIS development provides the opportunity to program an integrated m-business architecture into WEN framework from the ground up reducing overall system and integration costs over the long run.

B. MOBILE BUSINESS DEFINED

The concept of m-business is not new. Organizations employ different levels of m-business through mobile sales, repair services, and emergency response teams in order to extend the core competencies of the organization to field applications. That is, organizations optimize certain value adding processes, whether paper, radio or computer based, by extending the reach of corporate office assets to locations outside the office walls. Mobile business is not tied to technology, it is a user facing, value-adding concept in which field transactions and processing are integral pieces of the organizations business model. However, improvements in wireless network and mobile computing technologies make extending the organization's reach easier, more cost effective, and more data capable than in the past.

To develop a current working definition for wireless mobile business, one must look at current electronic business concepts and enabler mobile computing technologies that are making it more cost effective to employ. The Internet has made possible such concepts as electronic commerce (e-commerce), which is nothing more than the buying and selling of products and services over the Internet. E-commerce revolutionizes how

business is conducted and introduces “virtual stores” and “click and mortars” both which have gained widespread adoption by consumers.

E-business evolved from e-commerce. Electronic business includes e-commerce and all front and back office applications that drive modern business transactions (Kalkota & Robinson, 2002). To date, the e-business paradigm has centered on the wired Internet infrastructure and fixed or stationary users. However, advances in wireless networking and mobile computing combined with the widespread adoption of these technologies usher’s in the concept of mobile commerce (m-commerce).

Mobile commerce is simply defined as business transactions conducted while on the move. There is a lot of hype surrounding m-commerce and some initiatives may be too optimistic; however, m-commerce is likely to grow and mature as more users seek out ways to conduct business, communicate, and share information while away from their desks. Companies such as Federal Express, Progressive Insurance, and State Farm Insurance have identified key business aspects that are suitable for m-commerce. These companies are reengineering their internal business processes and employing mobile technology to reduce costs, improve productivity, and increase overall responsiveness to customer claims (Lykins, 2002). The natural extension to m-commerce is mobile business, which encompasses everything that happens behind the scene to enable m-commerce transactions from both online and offline mobile devices.

An implementation definition of m-business suitable for the mobile aircraft maintenance office concept can be derived by combining elements from Ravi Kalakota and Marcia Robinson (2002) and Nicholas Evans’ (2002) m-business equations:

$$\mathbf{M-Business = Process Reengineering + Internet + Wireless + E-business}$$

Process reengineering for m-business is the most critical and most difficult component of the equation. Without it, even the most effective combination of the Internet, wireless, and e-business technologies will likely result in failed m-business initiative attempts. Process reengineering forms the glue that holds the other three components together to create successful m-business initiative. For the mobile aircraft maintenance office,

process reengineering must lead the m-business initiative and will lay the foundation for a user centric design approach required to design and implement the concept.

The equation above reveals the complementary nature of m-business to present or evolving e-business initiatives. Not as easily seen from the equation are the unique aspects of the wireless components that compound m-business implementation. The wireless components, which include wireless networks and associated mobile devices, introduce different bandwidth characteristics and computing constraints that make the wireless Internet experience very different from the fixed wired Internet. These unique wireless characteristics include, but are not limited to, non-ubiquitous wireless coverage, variable bandwidth, different transmission protocols and device operating systems, varying display size and resolution, less storage capacity and significant battery life constraints. It is also important to note m-business encompasses both “always-on-and-connected” also referred to as “online” and the “on-demand” or “offline” mobile computing models. The choice of which model to implement is dependent on the nature of the organization’s business model. The “online” model supports real time transactions and information sharing whereas the “offline” model affords the user more ubiquitous access to critical information, however, requires synchronization via wired or wireless network after a transaction is completed.

It is important for naval information system decision makers to identify and understand the implications involved in integrating m-business capabilities into the next generation NALCOMIS. What differentiates m-business from e-business is the use of mobile computing and wireless technology. E-business is a tethered PC centric concept, whereas m-business extends the e-business model to an anytime and anywhere capability. To more accurately determine if the mobile maintenance concept is feasible, IT decision makers should survey the mobile landscape to gain insight into both the capabilities and the implications involved in extending e-business initiatives to include m-business applications.

C. THE MOBILE LANDSCAPE

Network infrastructure, hardware, and mobile application platforms housing the necessary middleware software comprise the mobile landscape. The m-business network infrastructure includes wireless local area and wide area technologies that encompasses terrestrial radio and satellite based systems, however the focus of this research will limit the discussion to terrestrial systems. The mobile device hardware discussion introduces issues unique to mobile computing devices. Lastly, an investigation into mobile application platforms will reveal the middleware functionality required to successfully extend suitable e-business initiatives to mobile users.

1. Wireless Local Area Networks (WLAN)

Wireless LAN technology has been a key enabler to local area m-business initiatives. It affords manufacturing and retail companies the capability to conduct real time inventories utilizing bar code scanning capable Personal Digital Assistants (PDA) that are wirelessly linked to the central inventory databases. Mobile business initiatives like the one mentioned above combined with the requisite process reengineering have resulted in increased productivity while reducing inventory accounting errors. There are many WLAN standards currently available and it is unclear which standard will likely be the predominant standard two years from now.

The Institute of Electrical and Electronics Engineers (IEEE) has put out a series of 802.11 standards that allow computer users equipped WLAN air interface cards to roam through a building while remaining connected to the wired network. These wireless systems have the ability to integrate into an existing wired Ethernet LAN or can form ad hoc, strictly wireless, network between two or more computers. The 802.11 series WLANs have an indoor radius of about 450 feet and about 1000 feet outdoors. Theoretical data rates range from 11 Mbps for the 802.11b to 54 Mbps for 802.11a standard. Competing WLAN technologies to the 802.11 standard are HomeRF and the European HyperLAN2 standards. Table 1 summarizes the predominant WLAN standards.

WLAN Standard	Description	Data Rate
802.11a	Next generation of 802.11. Debuted in late 2001 to early 2002. Located in unlicensed and less congested 5 GHz band	Up to 54Mbps
802.11b (WiFi)	Current wireless network standard designed for businesses. Located in unlicensed and congested 2.4 GHz range. Suffers from interference and security issues. Despite shortcomings has become the standard to beat	Up to 11 Mbps
802.11g	An extension of 802.11b to increase data rates. Expected to become future corporate choice due to backward compatibility with existing 802.11b products. Expected to become available end of 2002.	Up to 20Mbps and perhaps as high as 54Mbps
802.11e	Improves streaming media performance for all 802.11 systems. Attempts to unify and offer seamless interoperability between business, home and public environments. Expected to become available end of 2002.	N/A
Home RF	The alternative to 802.11b. Operates in same congested 2.4 GHz spectrum however more immune to interference than 802.11b. Uses shared Wireless Access Protocol.	1.6 Mbps
Home RF2	Second generation of HomeRF designed to boost throughput over original version. Operates in 2.4 GHz spectrum, but offers better voice and multi-media support.	Up to 10Mbps
HyperLan2	The emerging European standard. Likely to be a major contender in Europe operating in the 5 GHz spectrum	Up to 54 Mbps

Table 1. Wireless Local Area Network Summary.
(After: Kalakota & Robinson, 2002)

Employed in college campuses, office buildings, warehouses, residential homes, and Department of Defense (DoD) organizations, WLANs allow mobile computers to wirelessly access wired Ethernet networks and the Internet. Security has been the biggest drawback to WLAN deployment. Hackers are able to break the Wired Equivalent Privacy (WEP) security protocol to intercept and decrypt transmissions between the mobile devices and the access point and gain unauthorized access to an organizations private network. Wireless LANs are gaining widespread acceptance despite their security flaws and are rapidly becoming local area m-business enablers. Many computer manufacturers are keying into this growing WLAN acceptance and are shipping laptop computers and PDAs with integrated wireless LAN capability.

Wireless LANs, when combined with proper process reengineering and tailored e-business technologies, can increase the productivity of flight line maintenance personnel by eliminating the need to return to their respective shop desk top PC to enter transactions. This not only decreases the time an aircraft is delayed waiting for the transactions to be closed out, it frees maintenance personnel to begin work on other priority jobs.

2. Wide Area Wireless Data Networks

Though WLAN's are fundamental technology enablers for local m-business efforts, a wide area wireless network covering large geographic areas is required to truly enable "anytime and anywhere" aircraft maintenance management. A primary objective of this research is to understand the data capabilities of and limitations of current and soon to be introduced wide area cellular networks. Without a viable wide area wireless capability, the mobile aircraft maintenance office will likely be infeasible, as the link to the parent command will fail to be reliable.

Information systems decision makers need to understand how the cellular industry has evolved to better understand the implications, complexities, and constraints that affect present and future m-business network infrastructure. A detailed discussion of the evolution of cellular systems and their strengths, weaknesses and data capabilities is presented in Appendix A.

Data over cellular capabilities have matured from their humble beginnings in the early 1980's with the introduction of analog, Frequency Division Multiple Access (FDMA) system voice systems. These systems include the Advanced Mobile Phone System (AMPS), Nordic Mobile Telephone (NMT) and Total Access Communications System (TACS). The United States deployed AMPS, Europe deployed NMT and TACS and Japan deployed a modified version TACs called J-TACs. These 1G systems suffered from four major shortcomings: capacity (in terms of users per cell), security, quality of service, and no ability to transmit digital data⁷. Despite these shortcomings, 1G cellular systems were very successful and form the bedrock from which viable m-business enabling cellular technologies evolved. Although the 1G systems offer relatively comprehensive geographic coverage and are still in use, they only satisfy the mobile maintenance office's voice needs and are not suitable for the data requirements.

Today's cellular landscape evolved from the analog, voice only, first generation systems and now include more complex and secure Second Generation (2G), Two point Five Generation (2.5) and Third Generation (3G) digital voice and data networks. Each of these generations builds upon their predecessor's shortcoming while incorporating new

⁷ However, 1G cellular phones could serve as modems for mobile computers.

features perceived as required by the customer. Second generation systems introduced digital transmission techniques, greater capacity via Time Domain Multiple Access (TDMA) and Code Division Multiple Access (CDMA) technologies⁸, improved security, and the ability to directly transmit digital data. These networks relied on circuit switched technology for both voice and data services. The predominant 2G technologies are Global System for Mobile communications (GSM), IS-136 sometimes referred to as D-AMPS and IS-95A/B CDMA. According to Harte, Levine and Kikta, (2002) GSM is the world leader in digital cellular systems with over sixty percent of the global market share with CDMA capturing approximately twelve percent as of 2001.

All 2G systems have improved authentication and voice privacy capability and introduce new features such as Short Messaging Service (SMS) and web browsing via micro browsers. Reports indicate that SMS has become very successful and popular with consumers and businesses alike. However, the wireless web has failed to live up to consumer expectations primarily due to slow connection speeds averaging 10 kbps, Wireless Application Protocol (WAP) shortcomings, lack of suitable WAP friendly web sites, and the small monochrome displays on the mobile devices.

Second generation systems may satisfy the mobile maintenance office users voice and text data requirements, however, it is believed the user experience will be less than desirable due to the slow throughput and the less than satisfying wireless web capability. Packet switched technologies nor Internet Protocol (IP) are incorporated in most 2G-network systems. Large file transfers and multimedia services such as video conferencing are neither cost effective nor possible because of the low system data rates.

Cellular operators across the globe are currently migrating their 2G GSM, D-AMPS or IS-95A/B CDMA network platforms to either 2.5G or 3G networks in response to customer demands for higher data rates and multimedia services. Cellular data systems such as Cellular Digital Packet Data ⁹(CDPD), which are satisfactory for facsimile and short text only email transfers, may be giving way to more capable systems. Transitional

⁸ TDMA and CDMA are explained in Appendix A.

⁹ CDPD was designed as a digital packet switched, data only, system overlay to the existing AMPS networks capable of providing up to 19.2 kbps that is shared between the system's users.

2.5G systems use improved digital radio technology to increase data transmission rates and new packet based technology to increase system efficiency for data users (Harte, Levine and Kitka, 2002).

Cellular operators are integrating 2.5G digital cellular packet data systems into existing 2G networks and include General Packet Radio Services (GPRS), Enhanced Data Rates for GSM Evolution (EDGE) and CDMA2000 1xRTT technologies. These systems can provide theoretical data rates ranging from 64 kbps for IS-95B, 144 kbps for GPRS and CDMA2000 1X, and 384 kbps for EDGE. However, the two predominate 2.5G systems, GPRS and CDMA2000 1xRTT, have observed average data transfer rates of approximately 40-60 kbps under normal conditions. These improvements potentially bring the mobile maintenance office throughput and Internet experience up to the same quality as that experienced via 56k telephony modems. These enhancements offer improved voice, data, and web browsing capabilities over 2G systems and better meet voice and data requirements of the mobile maintenance office. However, large file transfers and video conferencing are still not feasible with the exception of EDGE and coverage is still limited when compared to 2G network coverage footprints but is expanding every month.

It is important to note, the choice of which 2.5G technologies an operator chooses to deploy is highly dependent on whether the existing 2G systems are TDMA (GSM or IS-136) or CDMA (IS-95) based. Refer to Figure 4 located in Appendix A for a more detailed description of the various migration paths towards 3G services. The GPRS and EDGE systems are not compatible with CDMA2000 1xRTT. In the United States, CDMA2000 1xRTT and GPRS/EDGE standards are deployed and impose coverage and compatibility issues for IT managers. For example Sprint PCS and Verizon Wireless are upgrading their 2G CDMA systems to CDMA2000 1xRTT while AT&T, Cingular, and T-Mobile are integrating GPRS into their existing TDMA based GSM networks. Unlike their European and Asian counterparts, American IT managers have to decide which network best meets their m-business initiatives coverage in North America and around the globe.

In response to customer demand for new features and services the International Telecommunications Union's (ITU) drafted plans for a third generation system called Universal Mobile Telephone System (UMTS) in the early 1990s. The original requirements for the system were defined in International Mobile Telephone-2000 (IMT-2000) specification. The global specification required the UMTS system to be capable of broadband data services, simultaneous voice and data operations (multi-media), improved system efficiency, and backward compatibility with 2G systems. Issues such as globally available common spectrum, operator migration costs, and other technological and political issues led to compromises in the original International Mobile Telephone-2000 (IMT-2000) specification. Appendix B presents the history, definition, and evolution of IMT-2000 in addition to spectrum issues and compromises that have added to the confusion surrounding 3G systems. These compromises resulted in multiple migration paths for cellular operators based primarily along existing 2G or 2.5G TDMA or CDMA lines and is summarized in Figure 6 located in Appendix B.

The different cellular platforms will likely coexist for many years to come as the ITU's vision of a completely new 3G UMTS global system appears unlikely to materialize as originally envisioned. Operators employing GSM and IS 136 are very likely to pursue GPRS/EDGE transitional implementations towards the Wideband-CDMA (W-CDMA) standard. Operators with IS 95A/B networks will likely integrate CDMA2000 1xRTT transitional technology while on the path to CDMA2000 Multi Channel (MC) standard. These two 3G platforms are likely to be the two most predominant platforms from the five that comprise the IMT-2000 specification. These diverging paths place barriers to network inter-compatibility that is key to true global roaming, thus complicating global m-business initiatives from a wireless network perspective. The result of this technology divergence will be felt more in the United States as different operators deploy competing standards unlike their European and Asian counterparts. Experts believe the answer to intersystem compatibility lies in the deployment of inexpensive multi-mode mobile devices. The successful development and deployment of these multi-mode devices is key to roaming between W-CDMA and

CDMA2000 networks and may prove critical in providing a global mobile aircraft maintenance capability.

The key improvements in 3G that are different than 2G and 2.5G cellular technologies include better packet data control, high-speed data transmission, multiple radio channel bandwidths and multiple channel data rates. W-CDMA and CDMA2000-MC achieve their superiority over 2G and 2.5G systems through improved modulation schemes, increased coding combinations, and the ability to group multiple channels to achieve the required bandwidth needed by a specific data service. Appendix C details W-CDMA and CDMA2000 concepts, components, and architecture that make them superior to previous cellular data services. As required by the IMT-2000 specification, these systems offer 144 kbps at vehicular speeds, 384 kbps at pedestrian speeds, and 2 Mbps in a stationary indoor environment. Both W-CDMA and CDMA2000-MC system data rates assume best effort quality of service. Actual data rates may be significantly slower based on the quantity of data users and the types of services requested, network load, and environmental conditions affecting radio frequency propagation.

The increased capacity, bandwidth, and improved services offered by 3G systems make them the mobile aircraft maintenance office wide area network of choice. It appears these systems will offer satisfactory bandwidth for voice, data, web browsing and multimedia requirements. These systems' larger file transfer, improved web browsing, and video conferencing capabilities enable fielded maintenance technicians, managers, and aircrew to effectively connect back to the parent command's knowledge base which was not possible with older cellular digital data services. However, these wireless networks provide bandwidth on demand and are constantly adjusting throughput based on network conditions. Additionally, a given mobile application has to satisfactorily deliver the requested information to a mobile device at the 144 kbps, 384 kbps or 2 Mbps (pedestrian, vehicular or stationary), and every throughput speed in-between. This requires a very different software application and infrastructure development approach than that for wired applications. Wireless m-business applications, especially those under the "online" model, require a more specialized infrastructure. This infrastructure must be

capable of handling these unique wireless network characteristics and optimize the content being delivered to the user for the given connection speed and network condition.

It appears improvements in wireless local and wide area networking offer technological enablers for modern wireless mobile business initiatives. Figure 2 provides a summary comparison of the different cellular networks. These technologies introduce new complexities, such as wireless security, “online” and “offline” transaction processing, and the delivery of tailored services to the user based on the conditions of the wireless network. Additionally, 2.5G and 3G networks are in their infancy. As of October 2002, Japan, Korea, Austria and the United States (very limited in scope) are the only countries that have deployed true 3G systems (3G is Here Today – 3G Operators, 2002). For the most part the United States and European operators are employing 2.5G transitional technologies on their way towards 3G and are expected to roll out full 3G capabilities within the next two years.

Decision makers must be very cognizant of the trends of the wireless industry as there is going to be a “shake out” period as different operators and vendors attempt to best position themselves to gain market share. Coverage areas, inter-network compatibility, and pricing schemes are likely to change considerably from their current state as the industry matures. Regardless of the wide area wireless network adopted, the mobile maintenance office infrastructure must provide a satisfactory user experience, add value to the process, and properly safeguard against unauthorized information disclosure and intrusion into the organizations private network.

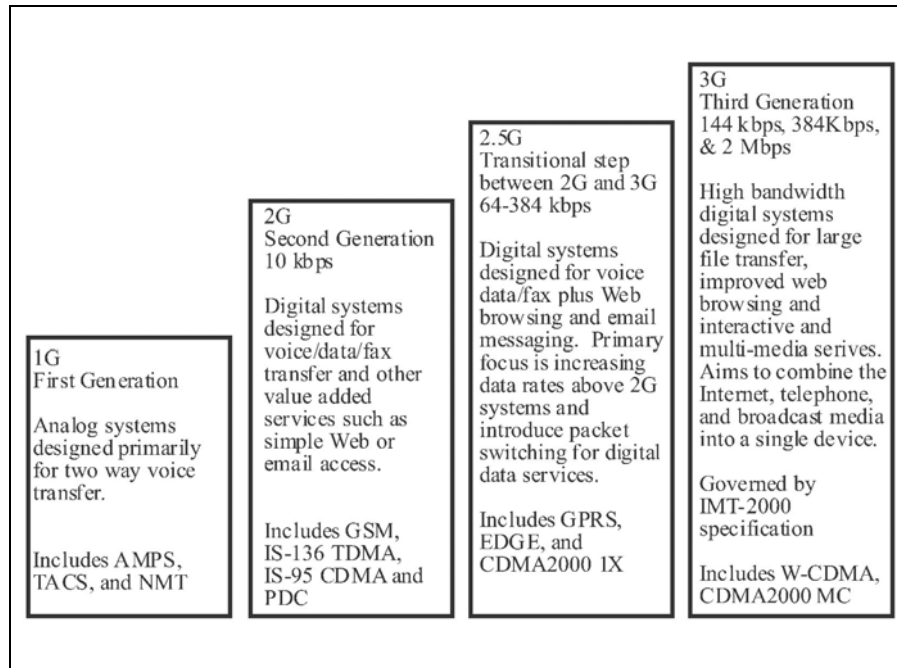


Figure 2. Comparison of 1G, 2G, 2.5G, and 3G Networks.
(After: Evans, 2002)

D. MOBILE DEVICE HARDWARE

The mobile device is the primary interface between the user and the voice or data information they are seeking. The world has seen mass proliferation of hundreds of mobile devices including pagers, cell phones, PDAs, sub notebooks and laptop PCs. It is not unusual to see people carrying around three, four, or five different portable devices each serving a different function. Fortunately, the recent trend is toward device convergence where one sees a single device performing multiple mobile functions. Examples include cell phones incorporating more computing features, commonly referred to as “smart phones” as well as PDA’s doubling as cell phones. Regardless of the “latest rage” in mobile device technology, it is important that chosen mobile device fits the functions required by the user in a way that maximizes user experience and mobile application effectiveness.

One sees the processor speed, memory, display quality, and functionality of mobile devices improving at break neck speeds. The goal of device manufacturers centers around three design features: compact form, high performance, and low power

consumption (Kalakota and Robinson, 2002). It is obvious, that with the exception of laptop PC, neither smart phone, PDA, nor sub notebook mobile devices match the computing power, memory, display or input characteristics of their desktop PC counterpart. Desktop PC processor clock rates recently surpassed the 2 GHz rate, while one the most powerful PDA processors, Intel's PXA250 Applications Processor, tops out at 400 MHz¹⁰. PDAs using this processor have 1/5 the processing speeds as that experienced by desktop users. This limitation when combined with the more complex operating systems, 65,000 color displays, increased memory capacities, audio and wireless networking interfaces, all which demand more of the processor's resources, mean that mobile software applications need to be very efficient.

A major consideration when deciding on a suitable mobile device is the display size and color characteristics. One does not have the same experience surfing the Web with a PDA as he or she would with a desktop computer. For one, most websites are not formatted for display on browsers that are smaller than 640 x 480 (Dornan, 2002). Secondly, resizing the aforementioned page to 320 x 240 does not necessarily fix the problem, especially if the compressed content (text and graphics) becomes too cluttered or small to be usable. This example does not even consider the various other smaller smart phone, PDA, and sub notebook display sizes or color characteristics. The display size and color issue is one of the main reasons why web enabled e-business initiatives do not necessarily translate directly into mobile business applications. The scenario is even more compounded when the target device is a smart phone. Their micro browsers require the use WAP and either Wireless Markup Language (WML) or Handheld Device Markup Language (HDML) instead of Hyper Text Markup Language (HTML).

To web-enable applications for use over the wireless Internet, HTML pages need to be converted and formatted for the specific mobile device. The majority of the configurable converter tools use XML as the intermediary language during the conversion process to support the generation of the output in different formats (i.e.

¹⁰ It is important to note that when comparing two different mobile devices, such as the Palm and the Pocket PC, clock speed is not a good metric for performance. In this case, the Palm has a 16 MHz processor while Pocket PCs have up to 400 MHz clock speeds. Both systems are comparable in performance, however the extra complexities of the Window CE operating system requires Pocket PC devices to have more computing power than their Palm counterparts (Dornan, 2002).

Wireless Markup Language (WML) for smart phones and HTML for PDA's). There is an integrated approach which combines an automated converter and an XML/eXtensible Style Language Transformation (XSLT) based transformation, which offers a framework that can be used either as an off the shelf product or extended to develop custom solutions. These integrated wireless suites are evolving to support not just the new generation of wireless content, but also HTML interfaces on PCs, enabling a website to support any form of client device (Ahmed, 2002).

A fundamental point in wireless mobile application development is that information is specifically tailored and presented in a way that is optimized for the mobile user's role and the device in use. A one size fits all approach will likely result in mobilized applications that do not meet the mobile users expectations or needs. One device may not fit all the user requirements, so the organization may very well be supporting multiple devices for a given wireless m-business application. For example, if a maintenance technician needs to access technical schematics from the mobile device, a PDA with a 240 x 320 display is an inappropriate device for this application. The opposite holds true when an application only requires reviewing small text pages or entering text into fields for a work request and a laptop or some other larger display device is used. In the later case, a PDA is the more appropriate choice. Nicholas Evans (2002) emphasizes the necessity in understanding the tradeoffs between the need to standardize on devices, operating systems, and applications and the need to give employees solutions that fit their specific work pattern behavior.

Another key implication with mobile devices is the types of user input interfaces. Laptops and sub notebooks usually include a standard QWERTY keyboard, however other wireless mobile devices use different input interfaces like handwriting recognition, soft keyboards, micro-keyboards, and telephone style keypads. Again, it is important to match the mobile application requirements to the most appropriate mobile device. Use-Cases and application requirements analysis should give insight into the type and quantity of data that the mobile user will enter via a mobile device. If a significant amount of text data must be entered, devices with full QWERTY keyboards might be the most appropriate. If requirements analysis determines only small amounts of text data will be

entered or if drop down boxes will be employed, a PDA with a micro-keyboard or handwriting recognition may suffice. If an organization fails to match the task to the proper device, it is likely to have negative consequences in terms of user satisfaction and could jeopardize the initiative.

But the key to mobile business applications is their ability to go anywhere and access data anytime. This requires extended operations on battery power. Despite advances in battery technologies, they have not kept pace with the demands of higher speed processors, wireless interfaces, greater memory capacity, and the bright 65,000 color displays. When designing the mobile business application, this factor must be a top concern. As cell phones and PDAs converge and more robust computing capabilities are demanded from the devices, battery life will prove to be critical in the mobile environment. To illustrate, A Compaq IPAQ 3850 contains a 1.4Ah lithium-ion polymer battery rated for approximately 10 hours of operation. Researching the validity of this claim Ed Neisley in his article Chemical Attraction (Dr Dobb's Journal, 2002), discovered that if one uses the Liquid Crystal Display (LCD) backlight and actually runs a few applications this time is reduced to about 3 hours. He goes further and points out that using an external plug in devices like a micro drive and a wireless link the time is further reduced to about 1.5 hours.

When reengineering a process for a mobile application, mobile device battery life and its impact on the system must be a top consideration. Mobile application requirements analysis should determine if power-taxing features such as 65,000 colors LCDs, 400 MHz processors, or large amounts of memory are required for the specific mobile function. Application development must also require the application software to be more processor and memory efficient in order to reduce power consumption. Additionally, it may be more economical from a battery management standpoint for the application to handle the transaction "offline", and then connect to the network for transmission. This seems contradictory to the notion of "always-on and connected" but may be necessary given the current battery technology. If the mobile application requires extensive "online" transactions then the device power consumption specification is critical and must be sufficient to handle the task. It is important to mitigate factors like

specific device hardware, software, and wireless networking requirements impacting battery consumption when developing a wireless mobile application.

E. MOBILE APPLICATIONS PLATFORMS

How does the mobile wireless infrastructure handle things mentioned above including variable bandwidth, different protocols, the multitudes of different device profiles, and the disconnected nature of mobile sessions? Also, how does a system adequately integrate the organizations security policy and provide connectivity to backend legacy systems? As one looks for a solution to address these requirements, it becomes evident some intermediary platform must be able to handle the unique characteristics of integrating mobile wireless applications.

The integrated m-business infrastructure must be adaptable and deliver the right content to the right person when they need it and in a suitable format for the device in use. Extending portions of NALCOMIS' e-business functionality to a number of different mobile devices creates a need for a single common infrastructure or platform (Kalakota & Robinson, 2002). The next generation WEN NALCOMIS will be designed for viewing on a standard desktop PC or notebook computer. Fielded technicians and aircrew will likely carry small screen mobile wireless devices that require optimizing the applications for quick data input and retrieval. If the "online" mobile model is chosen, the information going to the mobile user must be completely reformatted from its desktop PC format to ensure the best possible mobile user experience. It is imperative the mobile application platform provide fielded maintenance and aircrew personnel access to NALCOMIS information with no loss in transaction capability. It must also be able to deliver a consistent user experience based on the type of mobile device and wireless network connection speed.

The mobile application platform provides the specialized middleware required for mobile computing. The middleware must support multiple mobile devices. This means the middleware must be aware of the different device profiles and be capable of correctly identifying a user's particular device when requesting wireless service. It then adapts the web-based content and applications to meet the device's specifications, computing

capabilities and screen size, colors and mark up language formats. The integrated automated converter and an XML/XSLT based transformation implementation effectively illustrates this concept. In addition to adapting content and application to meet the specific device, the mobile application platform should be capable of optimizing the amount and format of content for delivery that is consistent with the mobile's connection speed.

An alternative to the “online” mobile model is the “offline” model employing intelligent database synchronization. Offline mobile applications require fat¹¹ mobile clients, but provide the field user with the necessary information whenever and wherever he or she needs it. This capability allows the user to conduct business transactions offline, then, when complete or back in range of the wireless network, synchronize with the main database to update the system. The ability to work offline to capture transactions, and then intelligently synchronize data on demand is key as spotty wireless network coverage and mobile device battery life may force the user to work offline. The synchronization middleware is critical to the “offline” model and must be able to intelligently detect changes in either database and either notify the user or automatically synchronize both databases. This ensures both the main and replicated databases match and reflect any transactions or updates that occurred while the user was offline.

Mobile synchronization technology may also offer a lower short and long term risk and cost reduction. System development risk and initial costs are mitigated, as synchronization technology is more mature and may require fewer components when compared to “always-on” type mobile technologies mentioned above. With regards to long-term cost of operating the mobile system, this technology reduces actual network connection time to that required for database synchronization, thus reducing the mobile devices air time bill. In his white paper titled “Mobile Enterprise Architecture - The Choices”, Jim Flynn (2002) offers an even less expensive way of handling offline synchronization in his “on demand” model. This model uses an enterprise database with a

¹¹ The Webopedia.com website defines a fat client, in the context of the client server architecture, as a client that performs the bulk of data processing operations. When the server performs the bulk of the processing operations and then presents the results to the client, the client is considered a thin client. In either case, the data is stored on the server.

back office application and reporting tool set that synchronizes across the Internet using FTP or email (Flynn, 2002). Flynn's research concludes that the initial cost of the "on demand" model is approximately eight percent less expensive when compared to an "always-on", real time, active synchronization model and is at least fifty percent less expensive annually to operate.

It is important to note, neither model was evaluated as superior to other, but should be chosen based on the requirements of the user and the mobile application stakeholders. Proper system requirements analysis and the envisioned operating environment will determine whether the mobile application should be an online only, offline only, or a combination of both. Regardless of mode, both online and offline systems fall under the mobile computing umbrella.

Additionally, the mobile application platform should be scalable providing cost effective support for future growth in the number of applications and user capacity. The platform should also facilitate the development, maintenance, and management of wireless capabilities as new applications and devices are introduced. It should support existing Web infrastructure security standards and policy. Most importantly, the mobile application platform should facilitate integration into existing e-business infrastructure. This feature is key to reducing the need to recreate existing functionality and content solely for wireless delivery.

When evaluating a vendor's product, the above-mentioned functionality serves as the minimum requirements for a suitable enterprise-class mobile application platform. Fortunately, middleware vendors like 724 Solutions, JP Mobile, Briece, and ViaFone are delivering high quality products that provide enterprise-class solutions to connect organizations internal business applications to their mobile forces.

F. SUMMARY

It is evident that enabling technologies such as 2.5G and 3G wireless networks, mobile devices, and mobile application infrastructure have matured to the point where they offer new value adding mobile business opportunities for naval aviation maintenance management. Existing local and wide area wireless networks are providing

adequate bandwidth to support the minimum voice and data requirements. The mobile force will benefit from third generation cellular network's videoconferencing and larger file transfer capabilities. However, e-business initiatives alone fail to account for the implications imposed in the wireless mobile environment. The combination of multiple radio protocols, the proliferation of hundreds of differing mobile device profiles, inefficiencies of TCP/IP in a wireless setting, information security over the air interface, unique data compression requirements, and the disconnected nature of mobile sessions all contribute to the complexities that require an adaptable mobile application infrastructure.

One of the most critical points to be made is the integration of necessary m-business infrastructure into the soon to be developed WEN NALCOMIS initiative. The business case for mobilizing certain time and manpower saving maintenance management processes is strong. The key is identifying the maintenance management processes that are most suitable for wireless mobilization. Decision makers should choose a relatively simple high-impact application that is capable of delivering a short-term return on investment from the list of candidate applications. If successful, the cost of establishing the mobile platform from which future mobile maintenance applications can be built can be justified.

III. MOBILE AIRCRAFT MAINTENANCE OFFICE REQUIREMENTS DEVELOPMENT

A. INTRODUCTION

Advances in mobile computing devices, adaptable infrastructure hardware and software, and the Internet combined with wireless technology serve as technological enablers that allow mobile users to capture aviation maintenance management transactions when and where they occur. Mobile maintenance applications can significantly facilitate information sharing between the fielded aircrew and maintenance managers at the parent organization and could result in fewer errors, more effective maintenance management, and significant cost savings in manpower and replacement parts when situations requiring remote maintenance arise. To explore the feasibility of a mobile maintenance office system and its benefits, it is imperative to choose a system design approach and employ a sound development process like the Unified Process (UP)¹² with the Use Case methodology to discover key functional user and supplemental requirements. This chapter will produce the basic artifacts associated with the UP's inception phase and includes the vision, Use Case model, and the first iteration of the supplemental specification. Once the basic functional requirements are developed, one can get a sense of system data flows and the basic infrastructure components necessary to better access the projects feasibility.

The complete mobile aircraft maintenance office will support, at a minimum, three primary field users: aircrew, maintenance technicians, and maintenance managers. Each user category requires a separate mobile maintenance office application; however, this chapter will limit the scope of study to the aircrew application of the mobile maintenance office. The process used to develop the aircrew application's vision, Use Case model, and functional and supplemental requirements is sufficient to determine the project's overall feasibility and is representative of the envisioned requirements for the mobile maintenance technician and maintenance management applications. The primary

¹² UP is used as an example process within which to explore requirements analysis and object oriented analysis and design. The process consists of four highly iterative and distinct phases: inception, elaboration, construction and transition (Larman, 2002, p. 14).

difference between the different applications is the user's information requirements and the type of mobile device used in the field. One can continue to employ the UP and expand on the artifacts derived in this chapter for the aircrew application to accommodate the requirements of the maintenance technician and maintenance manager. This is highly recommended to ensure an integrated mobile maintenance system and lower the overall system development costs. Regardless of user application, the basic mobile application infrastructure will be capable of serving all three user's mobile application needs regardless of mobile device employed.

B. DESIGN APPROACHES FOR DEVELOPING THE AIRCRAFT MOBILE MAINTENANCE OFFICE

When developing the aircrew mobile maintenance office application one can choose from three different and distinct approaches; device centric, application centric and user centric. Choosing the correct approach is critical to an organizations long-term mobile application implementation success.

1. Device Centric Approach

The device centric approach focuses primarily on each individual user device for a distinct version of given application. For each type of mobile device deployed, developers create a separate and distinct application. To illustrate, assume for a given mobile application, sixty percent of field users utilize a Windows based laptop computer to access the mobile application while thirty percent use Pocket PC PDA's and ten percent use smart phones. System developers develop and maintain separate applications for each the three devices employed. This approach leads to longer development times, makes upgrades difficult and expensive, and is not responsive to new user requirements or device technology. Employing this outdated approach results in a slow to deploy, expensive, and difficult to modify or upgrade mobile system (MobileQ, 2002).

It is foolish to think the mobile aircraft maintenance office concept will employ a single device across all communities or user categories. This fact combined with the diversity of mobile devices available and the need to properly match the mobile device to

the user's required tasks and form factor make this approach unsuitable for the mobile aircraft maintenance office.

2. Application Centric Approach

The application centric approach attempts to build a single mobile application that will function across multiple mobile devices. This "one size fits all" approach includes attempts to extend Web content to wireless devices through such mechanisms as transcoding and webscaping. This approach produces inherently unstable mobile applications that are poorly integrated into the enterprise architecture (MobileQ, 2002). The result of the application centric approach, which attempts to satisfy the majority of the user's need for a given device, is often a failure to deliver a satisfactory user experience on any device. A good example of an application centric approach can be demonstrated by accessing the Naval Postgraduate School's Website with a PDA that is wirelessly connected to the network. The PDA indeed displays the web page; however, the user must scroll up and down as well as left and right to see the page in its entirety. The result is a dissatisfying experience when compared to that of using a laptop or desktop PC.

3. User Centric Approach

The user centric approach is the most current and mature approach to mobile application development (MobileQ, 2002). This philosophy places the user experience at the forefront of development efforts rather than focusing on a particular device or application. The goal of this approach is to refine the user experience for different contexts without having to write, develop, and manage a distinct application for each type of device utilized. This approach is the only viable approach that can survive for the long-term in light of the blistering pace in which mobile device and wireless network are evolving.

Mobile application software developed using the device centric or application centric approach may result in technological dead ends without the ability to evolve or extend into the user centric paradigm (MobileQ, 2002). It is imperative that the mobile application development platform be user centric based and include tools for designing,

integrating, managing, deploying, securing and administering the mobile application. Researching different vendors that produce field force automation mobile application development platforms, such as Covigo, Sybase, and @Hand, it is apparent the user centric approach is the mobile application development methodology of choice.

C. EMPLOYING THE UNIFIED PROCESS TO DETERMINE BASIC FUNCTIONAL REQUIREMENTS

Use Case methodology within the UP framework greatly facilitates identifying and developing mobile aircraft maintenance office actors and functional requirements. All system notations, such as the Use Case diagram, employ the Unified Modeling Language (UML) standards. The following paragraphs represent the activities that occur during the inception phase of the UP. The goal of this investigation is to do just enough investigation to form a rational, justifiable opinion of the overall purpose and feasibility of the mobile aircraft maintenance application system (Larman, 2002). Ultimately, the results of this inception phase determine whether the project warrants further investigation and development.

1. The Aircrew Mobile Aircraft Maintenance Office Application Vision

The mobile aircraft maintenance office vision extends the parent organization's automated aircraft maintenance and aircrew flight information system to fielded personnel (terrestrial facilities only) while reducing the information transfer delay between fielded personnel and the parent organization from days to minutes. The mobile maintenance office system shall keep fielded aircrew, maintenance technicians and maintenance managers, and the parent organization decision makers better apprised of the latest aircraft and aircrew status. Additionally, the system shall facilitate voice, text, and imagery transfer to aid in communication, safety of flight determination, and damage assessment when situations warrant.

More specifically, the envisioned system will allow fielded personnel to review required aircraft maintenance information during short, out of area operations, and capture, process, and update new aircraft and aircrew information as if they were still at the parent organization. The system shall provide any newly entered information back to the parent organization's NALCOMIS system in addition to forwarding new aircraft

information from NALCOMIS to the fielded user. The mobile aircraft maintenance office system will build on and integrate with the WEN's e-business initiatives to add greater efficiency and effectiveness to remote aircraft operations and maintenance where wired Internet service may not be available.

The ultimate objective of this extended capability is to minimize transaction capture delay time, improve information flow between fielded entities and the parent organization, and reduce maintenance and manpower costs associated with remote operations/maintenance when compared to the processes employed today. The system will ultimately result in improved aircraft safety, mission effectiveness, and reduce maintenance costs and missed sorties due to the information delays and miscommunications.

2. Scope Refinement and Governing Instructions

As mentioned in the beginning of this chapter, the scope of the mobile maintenance office system will be limited to that of required by fielded aircrew¹³ users conducting routine, multi-leg, cross-country¹⁴ flights. The duration of the cross-country scenario used in this study spans from twenty-four to seventy-two hours. The Naval Aviation Maintenance Program (NAMP), OPNAVINST 4790.2 and the NATOPS General Flight and Operating, OPNAVINST 3710.7 instructions provide the basic information requirements for fielded aircrew personnel.

3. Maintenance Process Background Information

Flying a naval aircraft involves a four step administrative process: aircraft preparation, certifying the aircraft as "safe for flight", aircraft acceptance, and post flight accounting. As part of the preparation process, a plane captain first reviews the Aircraft Discrepancy Book (ADB)¹⁵ for discrepancies that are awaiting maintenance and recently

¹³ The OPNAVINST 3710.8S defines aircrew as military personnel on competent flight orders or civilian personnel whose duties require frequent and regular participation in aerial flights (U.S. Navy Department, 2001).

¹⁴ A flight that either does not remain in the local flying area or remains in the local flying area and terminates at a facility other than an active military facility.

¹⁵ The ADB provides the current status, material condition, configuration, and safe for flight documentation of an aircraft and is used by maintenance managers, technicians, and pilots in command in carrying out their aircraft maintenance and flight preparation responsibilities. It contains the AIA, all open and closed work orders for the last ten subsequent flights, consumption data, near due inspections and component removals (NALCOMIS OMA USER Guide, 2002).

completed work orders. He or she also reviews other data included in the ADB to get a feel for any trends in oil consumption. Next he or she performs both daily and turnaround inspections and annotates their completion in the ADB prior to the first flight of the day. The plane captain also signs the appropriate block of the Aircraft Inspection and Acceptance record (AIA)¹⁶, signifying the completion of the daily and turnaround inspection. This signature also marks the end of the aircraft preparation process.

Once the aircraft preparation process is complete the certification of the aircraft as “safe for flight” begins. A designated “safe for flight” releasing maintenance control supervisor reviews the ADB to ensure all required maintenance is complete, no outstanding maintenance will affect the mission, daily and turn around inspections are complete, and the aircraft is indeed “safe for flight” and ready for release to the pilot in command. The “safe for flight” releasing authority adds any applicable aircraft limitations or remarks to the “Limitations/Remarks” section of AIA and signs the appropriate block of the AIA certifying the aircraft is “safe for flight”.

Prior to accepting the aircraft for flight the pilot in command follows a similar process carried out by the maintenance control supervisor and is required by the two aforementioned instructions to:

- Review a record of aircraft discrepancies and corrective actions for the 10 previous flights. This information is contained in the ADB.
- Sign the AIA record assuming full responsibility for the safe operation of the aircraft and the safety of the other individuals aboard.

The post flight logging process consists normally of two activities; annotating new aircraft discrepancies discovered before, during, and after the flight and completing the Naval Aircraft Flight Record (NAVL FIR) form. Additionally, during cross-country operations, the pilot in command is also responsible for completing a “safe on deck” voice report to the squadron duty officer. This voice report serves to inform the operations office of the crew’s location and to close out that portion of the flight event on the squadron’s flight schedule.

¹⁶ This record is part of the ADB and is commonly referred to as the “A-sheet”.

The parent organization's NALCOMIS houses the database that contains the data tables and input forms that comprise the above mentioned automated ADB and NAVFLIR. NALCOMIS builds all the components that comprise the ADB through predefined queries built into the system. All the entities access the ADB information through a Windows based PC connected via an Ethernet LAN to the central NALCOMIS server. NALCOMIS captures the three signatures annotated on the AIA digitally.

The OPNAVINST 4790.2 allows for certain exceptions to accommodate out of area operations. The requirement to review the ADB prior to each flight still exists and the preflight and post flight processes still occur in some fashion and still must be captured and recorded by NALCOMIS. When the mission requires the aircraft to shut down at a non-local field overnight, the aircraft requires another daily and turnaround inspection. The OPNAVINST 4790.2H allows a squadron CO to authorize the pilot in command to conduct a pilot's preflight inspection to count in lieu of daily inspection for periods not exceeding seventy-two hours (U.S. Navy Department, 2001). This exception is primarily designed for single seat aircraft that cannot accommodate carrying properly qualified plane captains as aircrew. However, multi-seat helicopters and fixed wing often ensure the enlisted aircrew member is a qualified plane captain and is responsible for completing and documenting the daily and turnaround inspections. In either case, the pilot in command is responsible for certifying the aircraft "safe for flight" since a maintenance control supervisor representative is not available.

4. Product Perspective and System Boundary

The product perspective is an aircrew mobile maintenance application used by fielded aircrew to access and update the required aircraft maintenance and flight management programs and improve voice and digital communications while conducting cross-country operations. Fielded users will interface with the system through portable mobile devices. NALCOMIS will interact with the system via the parent organization's local area network and firewall. The mobile aircraft maintenance office application system includes mobile devices, an available public voice and data network, and the required servers and middleware in order to connect the fielded aircrew personnel and the entities (NALCOMIS and duty officer) residing in the parent organization. Everything

outside the aircrew mobile application system is outside the system boundary, which includes the fielded aircrew users and NALCOMIS.

5. System Goals

The mobile system shall provide fielded aircrews with the necessary automated capabilities to more effectively and safely conduct multi-leg, short duration (between twenty-four and seventy-two hours) cross-country operations regardless of location. The system should significantly reduce the delay in capturing and updating aircraft maintenance and flight transactions and improve communications between fielded aircrew and the parent organization's maintenance and operations supervisors. More specifically, the system goals include providing access to the required aircraft maintenance information, the ability to process the required maintenance and flight transactions to continue operations for up to seventy-two hours regardless of location, update the NALCOMIS database residing in the parent command, and to keep the parent command's maintenance managers and operations supervisors better informed about the current status of the aircraft and crew. Secondary goals include providing a means to enable voice and data communications to improve aircrew and aircraft status and provide a mechanism to transfer digital imagery to assist in damage assessment and field maintenance team composition decision processes.

6. System Constraints and Simplifying Assumptions

Based on the technology review conducted in Chapter II and the requirement that the fielded users shall have the required aircraft ADB information regardless of location, the system shall be capable of autonomous offline operations to facilitate field operations. Because of this constraint, the primary method of updating the NALCOMIS database will be via database synchronization versus "online" direct access method via a web browser. Transient aircrews are constrained by the austere services and facilities available to them while conducting cross-country operations. Because of this constraint, the system cannot rely on wired telephone connections as the primary means of accessing a public data or voice networks. Additionally, wireless voice and data network coverage is not ubiquitous and is also a factor requiring the system to be capable of "offline" operations. The final constraint is that the system's mobile devices cannot rely on external sources for power

and must be capable of operating on battery power for at least three days or have a means to recharge without relying on wired electrical outlets.

A key assumption is that a majority of civilian and military airports used by naval aircraft are located near populated areas and are within a commercial wireless service provider's coverage area. Additionally, it is assumed the wireless carrier's 2.5G and 3G-rollout schedule continues as planned and services are deployed nation wide. This implies that nationwide 2.5 or 3G cellular services will be available with at least the same coverage as is available with today's first and second-generation networks.

7. Identifying the Actors

Analysis of the broad functional requirements, process background, and system goals reveals at least five actors that will call upon the aircrew mobile maintenance application to assist them in conducting cross-country operations. Of the five actors, the pilot in command, plane captain, and NALCOMIS meet the definition of primary actors.¹⁷ Another primary actor to the system is the system administrator who will depend on the system to facilitate the system's administration. However, NALCOMIS' database also serves as the source database that provides the initial aircraft maintenance data to the system, which qualifies it as a supporting actor as well. Providing more data to the system than it receives, NALCOMIS is more of a supporting actor than a primary actor in this application. The duty officer and maintenance supervisor are off-stage actors, since they have an interest in the behavior of a Use Case but do not necessarily interact directly with the system (Larman, 2002).

8. User Characteristics

The bullets below succinctly describe how each of the primary and supporting actors mentioned above utilize the system to fulfill their needs.

- The **pilot in command** utilizes the system to review ADB information, process maintenance transactions required to continue cross-country operations, input completed flight data information, release the aircraft as "safe for flight", and make necessary voice and text reports for normal and exceptional maintenance and operational situations. Additionally, they would use the system to capture digital imagery for transmission to the parent organization.

¹⁷ Primary actors have user goals fulfilled through using services of the system under design. This is in contrast to supporting actors, which provide services to the system under design (Larman, 2002, p. 70).

- The **plane captain** utilizes the mobile system to review the required ADB information in order to properly conduct daily and turnaround inspections. He or she uses the system to access the appropriate inspection requirement cards and to capture the required preflight inspection transactions, process maintenance transactions, and digitally sign the appropriate block of the AIA.
- **NALCOMIS** interacts with the system to populate the remote database with initial aircraft maintenance data prior to the cross-county flight. Once the aircraft is detached, it provides and receives database updates to and from the system.
- The **system administrator** uses the system to manage users, security, and device configuration.

The two offstage actors, the maintenance manager and the duty officer, are omitted from the above discussion because they receive their benefits from components outside the system boundary. For example, the maintenance manager would receive updated aircraft maintenance information via the NALCOMIS system not the mobile maintenance office application system. Maintenance managers would also likely receive any data or digital image messages via the organization's email system not directly from the mobile application system. The same is true with the duty officer who would receive the "safe on deck" call via the normal telephone system and the NAVFLIR data via NALCOMIS and not the system under design.

The actors described above all have specific goals that they hope the mobile aircraft maintenance system will help satisfy. Craig Larman (2002) suggests that Use Case development for computer based applications focus at the Elementary Business Processes¹⁸ (EBP) or the user goal-level. Employing this strategy, one keeps the emphasis on the user and his or her goals while avoiding the common mistake of defining many Use Cases at too low of level; that is, a single step sub function or subtask within a EBP (Larman, 2002). Investigating user goals better assists in developing the Use Cases that define the aircrew mobile aircraft maintenance office application system's requirements. Actor-goal lists are simple tools used to document the actors and their

¹⁸ EBP is defined as "a task performed by one person in one place at one time, in response to a business event, which adds measurable business value and leaves data in a consistent state e.g., Approve Credit or Price Order" (Larman, 2002, p. 60).

specific EBP level goals. Each goal identified in the actor-goal list is later developed into a Use Case. It is important to note the process of defining actors, their goals, and the subsequent development of the respective Use Cases is highly iterative in nature and is not considered the final product at the end of the inception phase. Instead, the UP embraces changes to these artifacts as the developers and users progress through each of the remaining three phases, which usually results in better overall user satisfaction and system acceptance. Table 2 serves as the actor-goal list for the aircrew mobile aircraft maintenance office application system under design.

Actor	Goal
Pilot in Command (primary)	1) Access ADB information for specific aircraft 2) Process new AIA record 3) Process flight document (NAVFLIR) 4) Process new discrepancy 5) Synchronize database information 6) Capture digital images 7) Process text and data messages (e-mail) 8) Handle voice message transactions
Plane Captain (primary)	1) Access ADB information 2) Process Daily Inspection Record 3) Process Turnaround Inspection Record 4) Process new discrepancy 5) Access Daily and Turnaround Inspection Maintenance Requirement Cards (MRCs)
NALCOMIS (secondary)	1) Populate remote database 2) Synchronize database information
System Administrator (primary)	1) Manage users 2) Manage security 3) Manage device configuration
Duty Officer/Maintenance Supervisor (off stage)	1) Receive voice message transaction 2) Receive text and data messages (e-mail)

Table 2. Mobile Aircrew Maintenance Application System Actor-Goal List.

9. Use Case (UC) Development

The goals listed in Table 2 serve as the basis for developing Black-box Use Cases.¹⁹ During the inception phase, the Use Cases developed are in a brief terse one-paragraph format usually forming the main success scenario. Different actors listed in

¹⁹ Black-Box Use Cases are the most common and specifies what the system must do (the functional requirements) without deciding how it will do it (the design) (Larman, 2002, p. 49).

Table 2 share common goals and will be included in the applicable pilot in command Use Cases to minimize redundancy. The pilot in command actor goals from Table 2 are developed into brief format Use Cases below:

a. UC1: Access ADB

The pilot in command or plane captain arrives at the location of the aircraft and prepares to conduct his or her preflight inspection. Either user uses the system to access the pertinent data of the ADB to determine the mission capability and status of the aircraft. The system presents the user with the time stamp from the last remote database update and lists available options for the user to choose. The user chooses the ADB option. The system presents the user with an ADB submenu listing the open work orders, closed work orders, oil consumption, engine/APU/prop data, aircraft limitations/remarks, near due inspection, or component removal sections of the database and includes the number of records per section. The user chooses a section from the available options. The system presents the user with text data for the section chosen. The user navigates through each record for the applicable section. The system notifies the user when there are no more records for a particular section and returns to the ADB submenu. The user repeats the process until he or she is satisfied with the review of the ADB information. The user exits the system, departs for the aircraft and performs the preflight inspection.

b. UC2: Initiate New AIA

The pilot in command arrives at the aircraft location intending to initiate a flight. The pilot in command uses the system to generate and capture AIA record information in order to certify the aircraft as “safe for flight”. The pilot in command initiates a new AIA record. The system queries the pilot in command to ensure all the necessary data is entered in the AIA record’s fields and to verify the completion of the steps required to certify the aircraft “safe for flight”. The pilot in command enters the appropriate data or response to the queries. The system checks the open work order database to ensure there are no “Z” coded discrepancies, also referred to as downers, against the aircraft. The system prompts the pilot in command for the plane captain’s signature. The plane captain enters the correct information to digitally sign the appropriate block of the AIA. The system then prompts the pilot in command to sign and

certify the aircraft “safe for flight”. The pilot in command signs the appropriate block. The system validates and records the transaction (updates the remote database). The pilot in command initiates database synchronization with the local NALCOMIS database at the parent organization or exits the system.

c. UC3: Process Flight Document (NAVFLIR)

The pilot in command uses the system to record each flight during the cross-country evolution. The system presents the pilot in command with a list of options to choose. The pilot in command chooses the flight document option. The system presents the pilot in command with required empty data fields necessary to capture and record the flight data for a single or multiple legs as set forth by OPNAVINST 3710.7S. The pilot in command enters the data into the fields. The system validates and records the transaction. The pilot in command initiates database synchronization with the local NALCOMIS database at the parent organization or exits the system.

d. UC4: Process New Discrepancy

The pilot in command or plane captain uses the system to record new discrepancies (work orders) discovered before, during, and after the flight. The system presents the pilot in command with a list of options to choose. The user chooses the new discrepancy option. The system presents the user with a series of questions, prompts or fields to capture the necessary data fields. The user enters the appropriate text data. The system validates and records the transaction. The user repeats the process until he or she has finished entering all new discrepancies. The pilot in command initiates database synchronization with the local NALCOMIS database at the parent organization or exits the system.

e. UC5: Synchronize Database Information

The pilot in command uses the system to synchronize the local (NALCOMIS) and remote (mobile device) databases in order to improve aircraft and aircrew situational awareness with the parent organization. The system senses updates and any changes to the remote database (examples include: new AIA, flight document, or aircraft discrepancies) and determines the presence of network signal. The system prompts the user to initiate an “online” synchronization. The pilot in command initiates the synchronization processes. The system establishes a network connection, starts an

internal timer and synchronizes the two databases. The system closes the network connection, stops the internal timer, updates the synchronization time stamp, and logs the duration of the transaction when synchronization is complete. The system notifies the pilot in command the number of changes to the remote database. The pilot in command acknowledges the time stamp and changed information. The pilot in command reviews the remote database changes or exits the system.

f. UC6: Capture Digital Imagery

The pilot in command uses the system to capture digital images of aircraft components that have sustained physical damage. The mobile device will have the ability to serve as digital camera. The pilot in command uses the mobile device portion of the system to capture digital images of the area of interest. The system presents the image for review by the pilot in command. The pilot in command accepts the image and the system names and stores the image file in the mobile device's memory. The process repeats itself until the pilot in command is satisfied the damage has been accurately documented. The pilot in command exits the system.

g. UC7: Process Text and Data Message

The pilot in command uses the system to transmit and receive text and other data message to and from the parent organization. The pilot uses the mobile device portion of the system to compose a text message. The system presents the pilot in command with the required fields and text boxes to facilitate composing, routing, and adding attachments. The pilot in command enters the applicable data and appends any required attachments to be transmitted. The system validates the appropriate routing fields. The system establishes a network connection, starts an internal timer and transmits the message and attachments. The system receives incoming messages. Once the outbound and inbound transactions are complete, the system breaks the connection and logs the connection duration. The system informs the pilot in command that the transaction is complete and informs him or her of any new messages. The pilot in command reviews his or her new messages or exits the system.

h. UC8: Process Voice Message

The pilot in command uses the mobile device portion of the system to transmit and receive voice reports with the parent organization. The pilot in command

enters the parameters to contact the parent organization. The system establishes a network connection, passes the required routing parameters to the network, and starts an internal timer. The pilot in command transmits voice data via a microphone and receives voice data via a speaker. The system maintains a connection between the device and the network for the duration of the call. Additionally, the system alerts the pilot in command of any incoming voice transactions via an audible tone. The pilot in command accepts the call. The system starts the internal timer and maintains the connection until terminated. In either making or receiving voice transactions, the system closes the connection and logs the duration of the connection.

i. Other Use Case Development

As mentioned, the Use Case development was limited to the pilot in command goal list for the sake of brevity. The information gained from the pilot in command Use Cases is sufficient to begin making decisions on the systems feasibility. Again, the goal of the inception phase is to collect enough information to establish a common vision, determine the feasibility of the project and whether it is worthwhile continuing the investigation. The Use Cases above will go through much iteration as they progress through the UP. Larman (2002) suggest the primary focus during the inception phase is on understanding the basic scope and about ten percent of the requirements, expressed in textual form (p.101). It is important to note as the system's development progresses into the elaboration phase and spirals through multiple iterations, more Use Cases are written and rewritten in detail until about eighty to ninety percent of them are "fully dressed".²⁰

The UP suggests about ten percent of the brief Use Cases be reworked into a "fully dressed" format during the inception phase. The database synchronization Use Case is detailed due to its complexity and technical risk when compared to the other Use Cases. The fully dressed Use Case helps refine and clarify the goals, tasks, and requirements of the aircrew mobile maintenance application system with regard to

²⁰ Fully dressed Use Cases include all steps and variations that may occur in a given scenario. A fully dressed Use Case may include such items as stake holder interests, preconditions, post conditions, the main success scenario, alternative flow scenarios, special requirements, technology and data variations list, frequency of occurrence and open issues. (Larman, 2002)

database synchronization goal. The second iteration of the fully dressed synchronize database information is detailed below.

10. Synchronize Database Information (Fully Dressed Format)²¹

Primary Actor/s: Pilot in Command; NALCOMIS database

Stakeholder and Interests: The pilot in command wants the mobile portion of the system to automatically connect and synchronize with the parent organization's NALCOMIS database to reduce fielded aircraft and aircrew data delay times and improve overall aircraft safety and situational awareness during short duration cross-country operations. He or she wants a fault tolerant system that is capable of using more than one type of network to connect to and synchronize with NALCOMIS. If changes have been made in the remote database and the system has been unable to synchronize, the pilot in command wants to be reminded to attempt synchronization each time the mobile portion of the system is accessed. After a successful synchronization, the pilot in command wants notification of the completed synchronization and if any changes to his or her remote database were made.

The NALCOMIS database wants its local database to accurately reflect the maintenance and flight data transactions that have occurred against the fielded aircraft to better keep the maintenance supervisors informed of aircraft and aircrew status. It also wants to update the remote database with any new discrepancies that affect the fielded aircrafts status (e.g., lost tool, safe for flight technical directive, etc...).

The parent organization wants more timely aircraft maintenance and flight data transaction capture to improve situational awareness. This includes new discrepancies against the aircraft, actual flight hours charged against the aircraft and crew, and any complete or incomplete mission qualifications achieved during the flight, which may affect follow on aircraft or aircrew tasking upon return. The parent organization wants a mechanism to review connection times to validate billing charges.

²¹ The format of the fully dressed Use Case is fashioned after Craig Larman's (2001) example and was derived from the template available at www.usecases.org.

Preconditions: The mobile device portion of the system is turned on and its remote database is populated. The pilot in command wishes to check the local NALCOMIS database for any new discrepancies or the mobile device portion of the system has notified the pilot in command that “new transaction have occurred since last synchronization”. The NALCOMIS server is available and online. The system is properly configured to accept and transmit data to and from the fielded portion of the system. Either a wireless network or wired telephone line is available.

Post Conditions: The pilot in command’s mobile device’s remote database is synchronized with the parent organization’s NALCOMIS database to provide the most accurate aircraft and aircrew data. All transactions that have occurred during the cross-country have been saved in the parent organization’s NALCOMIS database. All stakeholders are informed or have the ability to check the current status of the aircraft and crew. The pilot in command is notified of the latest synchronization and if there were any changes to the remote database. The system logs each transaction’s connection time.

Main Success Scenario (Basic Flow):

1. Pilot in command initiates synchronization event from mobile device.
2. The mobile portion of system (mobile device) detects the presence of a wireless network, queues the correct IP address and connects to the system’s mobile synchronization server.
3. Once the mobile device is properly identified and authenticated by the wireless network, the mobile device starts in internal timer.
4. The mobile device passes the aircraft bureau number, in addition to the date and time of the remote database’s last transaction to the synchronization server portion of the system.
5. The system synchronization server establishes a connection with the NALCOMIS database.
6. The synchronization server queries the NALCOMIS system for the date and time of the local database’s last transaction pertaining to the fielded aircraft.
7. NALCOMIS returns the time and date of the last transaction as it pertains to the aircraft in question to the system’s synchronization server.

8. The system's synchronization server determines if synchronization is required and performs functions to synchronize both the local NALCOMIS and remote databases.
9. When complete with successful database synchronization, the system's synchronization server logs the date and time in its synchronization database. It then passes the synchronization date and time to the mobile device portion of the system and NALCOMIS.
10. The synchronization server breaks the connection with NALCOMIS.
11. The mobile device portion of the system updates its synchronization log.
12. The mobile device portion of the system terminates the network connection to the system's synchronization server and the wireless network, and halts the internal timer.
13. The mobile device portion of the system passes connection date, time and duration to its connection log.
14. The mobile device notifies the pilot in command of latest synchronization date and time, and if any changes were made to the remote database.

Extensions²² (or Alternate Flows):

- a. At any time any portion of the system fails:

The mobile portion of the system must ensure remote database information can be recovered from any step of the scenario.

1. The pilot in command restarts the mobile portion of the system, and requests recovery of data to pre-synchronization state.
2. The mobile portion of the system reconstructs the remote database to its pre-synchronization state.
 - 2a. Mobile portion of the system detects anomalies preventing successful recovery:
 1. Mobile portion of system notifies the pilot in command of error, records the error, and enters a clean state.
 2. The pilot in command starts a new synchronization session.
 - 2a. In the event of the system fails to detect an available wireless network:

²² Extension scenarios are branches from the main success scenario, so are annotated with respect to it. For example, at Step 2 of the main success scenario, the system may be unable to detect a wireless network due to a coverage gap. An extension is labeled "2a"; it first identifies the condition and then the response also called handling. Alternate extensions at step 2 are labeled "2b" and so forth. At the end of extension handling, by default the scenario merges back with the main success scenario, unless otherwise noted.

1. The mobile device portion of the system terminates the synchronization sequence and notifies the pilot in command that a wireless network is not available. The system shall recommend using a telephone connection if available.
 - 1a. If a wired line is available:
 1. The pilot in command connects the mobile device to the wired interface.
 2. The mobile device detects the presence of wired phone line and automatically dials the synchronization server's dial up Remote Access System (RAS).
 3. System performs database synchronization over the wired connection.
 - 1b. If a wired line is not available:
 1. The mobile device portion of the system will continue monitoring its network adapter for connection status and notifies the pilot in command when it detects the presence of an available wireless network.
- 2b. If mobile portion of system fails to connect to synchronization server:
 1. The mobile device terminates connection after predetermined number of attempts.
 2. The mobile device of the system notifies the pilot in command that synchronization attempt failed and offers the pilot in command the option to re-attempt connection.
 3. The process repeats itself until either a successful connection is made or the pilot in command chooses to terminate synchronization attempts.
- 8a. In the event the system synchronization server determines synchronization is not required:
 1. The synchronization server logs the date and time in its synchronization database. It then passes the synchronization date and time to both databases and a "no synchronization required" message to the mobile portion of the system.

Special Requirements:

- All data sent via public data networks must be encrypted in accordance with DoD Information Security guidelines.

- Synchronization should be completed within 2 minutes ninety percent of the time.
- Two methods of accessing the synchronization server are required to increase system availability.

Technology and Data Variations List:

- 2a. Wireless network may be a 2G, 2.5G, or 3G cellular systems.
- 3a. Mobile device requires Electronic Identification Code (EIC) to identify and authenticate itself to the wireless network.

Frequency of Occurrence: Up to 10 times per day.

Open Issues:

- What 2G, 2.5G or 3G standard should be employed?
- What synchronization standard should be employed?
- How do you identify and authenticate the mobile user to the mobile device prior to synchronization?

11. Use Case Diagram

With the Use Cases drafted, one can use UML notation to develop a diagram notation that illustrates the names of the Use Cases, the actors, and the relationship between them. Figure 3 is the aircrew mobile maintenance office application Use Case diagram.

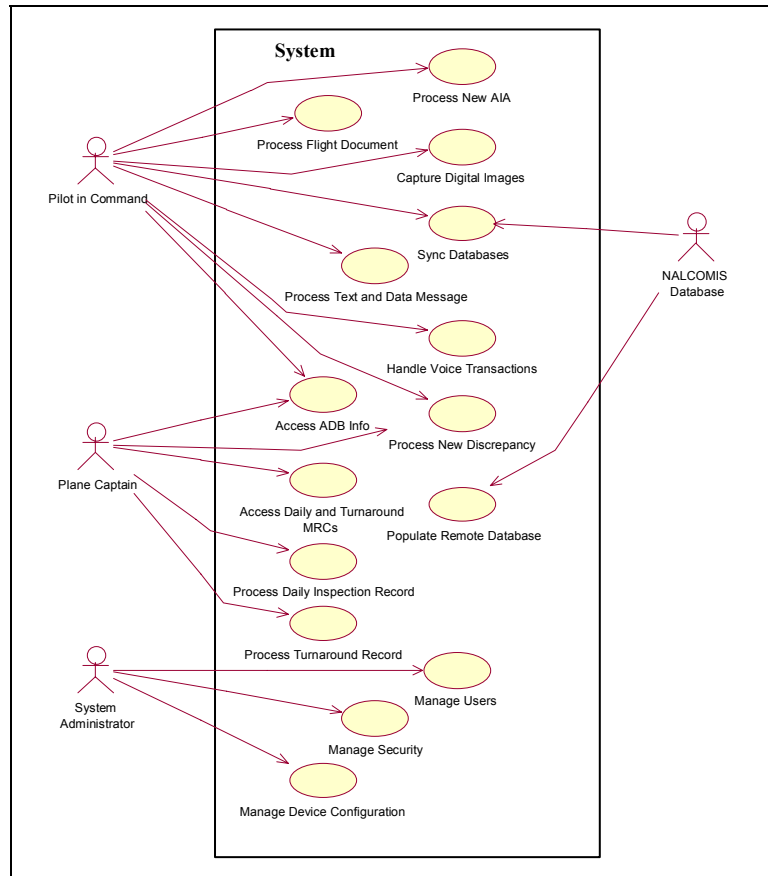


Figure 3. Aircrew Mobile Aircraft Maintenance Application Use Case Diagram.

The Use Case diagram provides a clear, succinct visual aid to help put the system in proper context. It effectively does this by clearly showing the boundary of the system, what lies outside of it and how the system is used. From the Use Case diagram above, developers and users can more easily visualize the behavior of the system and its actors. Note that the Use Case diagram was derived from the actor-goal list and the developed Use Cases and primarily serves as a quick visual summary of the system and its behavior. Craig Larman (2002) emphasizes the majority of the development team's efforts should concentrate on writing text (Use Cases) versus drawing Use Case diagrams or hashing out Use Case relationships during the inception phase. The above diagram is nothing more than a visual communication tool between developers and the system's users.

12. Developing the Supplementary Specification

Use Case development provides the framework to consider and organize the aircrew mobile aircraft maintenance office application system's functional requirements

and determines the projects feasibility via simple, user-based scenarios. The UP in conjunction with Use Case development is designed to replace the more traditional method of creating low-level feature lists²³ in order to derive function requirements. Use Cases help define the functional requirement of the system; however, they do not always account for some other non-functional requirement that fall into to Usability, Reliability, Performance, and Supportability (URPS) categories.

One of the last major artifacts of the inception phase is the supplemental specification. In addition to listing the functional requirements derived from the Use Cases, the supplemental specification captures URPS requirements, information, and constraints that may not be derived directly from Use Cases. The inception phase's supplemental specification artifact is not a finished product but rather the first draft of an important document which undergoes many more iterations as the project progresses through the UP.

The emphasis of this research will be in deriving the initial Functionality, Usability, Reliability, Performance and Supportability (FURPS) requirements. The functionality requirements will be primarily derived from the actor goal list and Use Cases. Non-functional or URPS are derived based on system goals, the technology research in Chapter II and the appendices, and any foreseeable constraints. Tables 3 and 4 below summarize the functionality and other requirements for the mobile maintenance application system and are the main item in the supplemental specification. The envisioned function's relation with regards to core functionality or its perceived complexity determines the development priorities column value. The goal of the prioritization is to mitigate the most risky items early in development when changes to requirements are the least expensive.

Reference No.	Function	Development Priority *	Use Case Association
F0001	Mobile portion of system shall do wireless network detection.	A	Synchronize Databases
F0002	Mobile portion of system shall do connection and termination with	A	Synchronize Databases

²³ Low-level feature lists are common in traditional requirements methods and often result in very long and detailed function lists that do not relate requirements in a cohesive context (Larman, 2002).

Reference No.	Function	Development Priority *	Use Case Association
	synchronization server portion of system.		
F0003	Mobile portion of system shall notify the pilot of command of last synchronization time and date and if remote database information has changed.	A	Synchronize Databases
F0004	Synchronization server portion of system shall do connection and break connections with NALCOMIS database.	A	Synchronize Databases
F0005	Synchronization server portion of system shall do wireless synchronization of remote and local databases.	A	Synchronize Databases
F0006	Mobile portion of system shall provide user with all pertinent ADB information in an “offline” mode.	A	Access ADB
F0007	Mobile portion of system shall facilitate user signatures similar to NALCOMIS	A	Initiate New AIA, Process Flight Documents, Process daily and turnaround inspection Use Cases
F0008	Mobile portion of system shall do NAVFLIR Data capture.	A	Process Flight Documents
F0009	Mobile portion of system shall do new aircraft discrepancies capture.	A	Process New Discrepancy
F0010	Mobile portion of system shall capture and store digital imagery.	A	Capture Digital Images
F0011	Mobile portion of system shall be capable of composing text messages.	A	Process Text and Data Messages
F0012	Mobile portion of system shall do two-way wireless voice communications with parent command.	A	Process Voice Transactions
F0013	Mobile portion of system shall allow user to enter parameters to contact parent organization. (Ex Phone number or IP address)	A	Process Voice Transactions
F0014	Mobile portion of system shall allow user to sign off completed individual and multiple Daily and Turnaround MRC items.	A	Process Daily Inspection Record, Process Turnaround Inspection Record
F0015	The system shall do remote database initial aircraft data population.	A	Populate Remote Database
F0016	Mobile portion of system shall do network connection time monitoring.	B	Synchronize Databases
F0017	Mobile portion of system shall notify the pilot in command when a wireless network is not available.	B	Synchronize Databases, Process Text and Data Messages, Process Voice Transactions
F0018	Mobile portion of system shall be do alternative remote and local database synchronization over wired connection. (RAS)	B	Synchronize Databases
F0019	Mobile portion of system shall do data entry validation to ensure correct data type for NALCOMIS	B	All data entry Use Cases

Reference No.	Function	Development Priority *	Use Case Association
F0020	Mobile portion of system shall be capable and transmitting text messages over a wireless and wired network.	B	Process Text and Data Messages
F0021	Mobile portion of system shall be capable of appending attachments to text messages.	B	Process Text and Data Messages
F0022	Mobile portion of system shall allow user to access inspection MRCs in “offline” mode.	B	Process Daily Inspection Record, Process Turnaround Inspection Record
F0023	System shall allow for easy management of users and passwords for mobile devices, and system access.	B	Manage users
F0024	System shall be capable of secure operations over public networks using DoD accepted encryption standards that is centrally managed	B	Manage Security
F0025	System shall be capable of over the air provisioning to facilitate security and configuration management of the mobile devices	B	Manage Security, Manage Device Configuration
F0026	Mobile portion of system shall log all synchronization events.	C	Synchronize Databases
F0027	Mobile portion of system shall log all connection durations.	C	Synchronize Databases
F0028	Synchronization server portion logs all synchronization events.	C	Synchronize Databases
F0029	Mobile portion of system shall be capable of storing multiple digital images.	C	Capture Digital Images
* A= High design priority, B= Medium design priority, C= Lower design priority			

Table 3. First Iteration Functional Requirements List.

Reference No.	Function	*Category	Detail and Constraints
O0001	The system should support multiple types of mobile devices	U	Different aviation communities may require different devices for the identified users. Also allows the system to take advantage of improved technology when available
O0002	The mobile portion shall be ruggedized and capable of battery operations for up to 72 hours.	R	The mobile device is expected to operate in a non-office type environment. Electrical outlets may not be available
O0003	The mobile device screen shall be readable in bright sunlight and at night	U	The fielded device will be used primarily in outdoor flight line environment.
O0004	The mobile device software should be written once and support multiple types of device	S	Many mobile studio packages support user centric approach

Reference No.	Function	*Category	Detail and Constraints
	platforms.		concept in that the program is written once and can automatically generate the code required by multiple supported devices. Allows for the use of differing mobile devices and for the rapid technological obsolescence associated with mobile device platforms. Supports User Centric Approach paradigm.
O0005	The mobile portion of system should be menu driven.	U	Facilitates user friendliness and is the accepted standard program interface standard.
O0006	The system components should utilize non-proprietary language and standards.	S	To extend the life of the system and to ensure it is compatibility with other mobile systems to support future interoperability.
O0007	The system shall utilize TCP/IP protocol.	S	Leading non-proprietary networking standard
O0008	The system shall be capable automatically adjusting synchronization services for varying wireless bandwidth conditions.	P	Wireless network bandwidth inherently fluctuates considerably more than wired networks. System must adapt and adjust throughput to minimize errors.
O0009	The system shall be best positioned to take advantage global roaming	S	The (2.5G) GPRS/(3G) W-CDMA wireless network likely to at least 2/3 of world market share compared to CDMA2000.
O0010	The system shall use a wireless network capable of minimum throughput speeds comparable to a 56kbps modem, but should be capable of broadband speeds	P	The wireless network should be capable of broadband data transfer speeds to be cost effective. As a minimum, the system must be comparable to current wired modem speeds.
O0011	The system shall be capable of providing required information and data capture capability 24 hours/7days a week regardless of location.	P	System must support "offline" operations due to wireless coverage holes and austere conditions experienced at military and non-military airfields.
O0012	The system shall be capable of recovering original data incase of error during synchronization	R	The fielded users must be able to restore the database to the pre-synchronization attempt condition.
O0013	A single mobile device shall be capable of all system functions (i.e. data review/entry, phone, camera).	U	Takes advantage of device convergence trend. The mobile device can use sleeves

Reference No.	Function	*Category	Detail and Constraints
			and adapters to meet requirements, however it must be auto configurable.
O0014	The mobile device shall be as small and light as possible for the given information requirements.	U	Storage space in many types of aircraft is at a premium. Additionally, the austere environment of flight line operations is not optimized for larger mobile devices. PDA/ Smart phone recommended.
O0015	The mobile portion of the system should have a windows look and feel.	U	The Navy employs windows based products, thus users are most comfortable using windows based products.
* U= Usability Requirement, R= Reliability Requirement, P= Performance Requirement, S= Supportability Requirement			

Table 4. First Iteration of Non-Functional (URPS) Requirements List.

The FURPS tables derived above are the two major components of the supplemental specification. By no means at this stage are they all-inclusive; however, they provide the beginnings of a solid, user centric, requirements list that assists in mapping system functionality to a specific user focused requirement specification.

As previously mentioned, the UP is highly iterative and every artifact derived to this point will undergo many iterations in the elaboration phase where they are further detailed and refined. Key Use Cases will eventually evolve into UML interaction diagrams consisting of collaboration and system sequence diagrams, which aid in understanding complex branching, iteration, concurrent behavior, and the sequence and timing of messages. This process aids in making major design decisions.

D. SUMMARY

In review, the goal of the inception phase is to establish an initial common vision for the aircrew mobile aircraft maintenance office application project and determine some of the FURPS requirements which to better assess the feasibility of the project. Using the artifacts derived above, developers and users begin to piece together some of the required components, software functionality and networking technology that is required to bring

the system to fruition. It also provides the necessary information to determine if the proposed system warrants a more serious investigative effort in the elaboration phase.

The artifacts produced from the inception phase of UP are also useful in evaluating specific vendor mobile application development suites, hardware, and networking solutions. The process yields an excellent base of functional and non-functional requirements that serve as a checklist to better assess the vendor's product and its ability to meet the organization's goals. The inception phase is designed to be accomplished in a few days and does not involve heavy investment of capital. Most importantly, Use Case generation within the UP framework supports the user centric paradigm and is more likely to result in a system that maximizes the user experience. UP involves users early, keeps the focus on the users goals, and is better positioned to achieve user acceptance and "buy in" which is critical to system implementation.

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IV. CONCLUSION

A. CONCLUSIONS

Based on the research conducted in Chapters II, III, and Appendices B and C the aircraft mobile maintenance office project is a viable concept that adds value to the naval aviation maintenance system. The research defined mobile business and identified an implementation definition whose elements²⁴, when combined, make the aircraft mobile aircraft maintenance office plausible. Extending Optimized NALCOMIS, within the larger framework of the Navy's current WEN initiative, to mobile users serves as the e-business and Internet components of the implementation definition. GPRS, CMDA2000, and W-CDMA provide possible wide area wireless network solutions that promise increased data speeds and enhanced wireless services to customers. Adopting the user centric paradigm and employing the UP design approach in developing a mobile system leads organizations to utilize scenario-based Use Cases to discover a common project vision, mobile user processes, and the functional requirements of the system. Exercising user-based scenarios to derive functional requirements in addition to the UP's use of iterative prototyping and user feedback mechanisms forces an organization to properly engineer or re-engineer mobile application processes. It important to reiterate that process re-engineering is probably the most critical component in positioning an m-business initiative for successful implementation.

Improvements in mobile device computing power, memory storage, and battery life extension capabilities improve the likelihood of mobile business adoption. These mobile device improvements combined with the trend toward device convergence serve as a positive multiplier in the mobile aircraft maintenance office system. Specifically, if different functionality is modularized it affords the system added flexibility and scalability. For example, mobile aircrew using a Hewlett Packard IPAQ h5450 PDA²⁵ has enough computing power and memory to handle the mobile application and database

²⁴ M-business = Process re-engineering + Internet + Wireless + E-business.

²⁵ This device comes standard with Intel's 400 MHz Xscale process, 64 Megabytes of Random Access Memory and 48 Megabytes of Flash Read Only Memory. It also has a built in memory expansion slot for Secure Digital Memory Cards providing up to 128 Megabytes of additional memory space (HP iPAQ Pocket PC h5450, 2003).

requirements in addition to already having a built in mobile e-mail application and 802.11 wireless card. Additionally, the mobile device has the added flexibility of accepting expansion packs that allow the device to integrate GPRS, W-CDMA, or CDMA2000 series wireless Compact Flash (CF) cards and serve as a digital camera.²⁶ The above described IPAQ, using Nexiam's Nexicam camera expansion pack with a Sierra Wireless GPRS wireless network card installed in the CF expansion slot, serves a mobile computer, camera, and phone yet essentially maintains the footprint of a single device. This type of modularity is a direct result of the device convergence trend and enables a single device to meet the data, imagery, and voice requirements of the aircrew mobile aircraft maintenance office.

Furthermore, this modular design has an added advantage in that it allows for future developments without running the risk of complete device obsolescence. For example, suppose the CDMA2000 3G standard is adopted for the mobile aircraft maintenance office system based on its dominant market share in the United States. While on deployment, a squadron sends two aircraft to an airbase in Italy to conduct low-level navigation training flights for two days. Unfortunately, the 3G standard in Europe is W-CDMA not CDMA2000 and the two 3G systems are not compatible (this is in spite of the original ITU specification's global roaming vision). All that is required to get the system operational again is a quick swap out in the wireless CF card. The rest of the system is unaffected. This scenario assumes the aircraft carrier has Internet capability and that the Navy's primary wireless carrier has partnered with European wireless carriers to provide global coverage. Although the examples above used a Windows CE operating system based device, other devices based on the Palm, Symbian, or Linux operating systems also have similar modular expansion capabilities.

Another key finding was that mobile computing did not necessarily equate to wireless computing. Many experts point out that organizations mistakenly plan or build their mobile applications based on promised services of 3G wireless networks. To avoid this mistake these experts recommend focusing on "mobile applications" versus "wireless

²⁶ Sierra Wireless is one vendor who provides third party cellular network CF cards. Nexiam provides a digital camera expansion pack for the IPAQs and includes a slot that could accommodate a variety of CF cards to include wireless networking cards.

applications” in order to better position m-business initiatives. This argument in conjunction with understanding that mobile computing includes both “online” and “offline” models aids in better assessing high level functional requirements. Decision makers are forced take a hard look into information requirements of the purposed system to decide which mobile model is the most appropriate. With regard to the aircraft mobile maintenance office, it becomes clear that there is no justifiable argument for the system to be a “real time” system and that a “near real time” system will suffice. This discovery greatly simplifies the problem, reduces the design costs, mitigates some of the wireless and adaptable infrastructure risks, and makes for a truly mobile system.

The decision to use “offline” technology requires a “fat” mobile client in order to process the replicated database data into the proper presentation and format for the mobile users. This is opposed to a browser based “online” model using a “thin client” that uses active server pages to query the database and provide the data in real time directly from the server. Advantages in choosing the “offline” over the “online” include:

- Compensates for the holes in wireless network coverage.
- Reduces airtime costs to that required for synchronization.
- Allows for a truly mobile system that the end user can rely upon anytime and anywhere.
- Unlike an “online” system the “offline” model is not as dependent on the proposed 3G increased data rates in order to deliver a satisfactory user experience.
- “Offline” system infrastructure is less complex than “online” systems. “Offline” systems do not require complex XML/XSL transformation middleware to transform or convert existing web pages into a format optimized for the specific mobile device nor does it have to continually adjust content for existing network conditions.

The key advantage of the “offline” model is that it is not totally dependent on the promised service and capabilities of 3G networks and can function in 2G or 2.5G network environments. This allows naval aviation maintenance decision makers to develop and deploy this system now while providing the necessary flexibility in case cellular operators slow or abandon their efforts to deploy the expensive 3G upgrades.

Although the “offline” model offers a seemingly less complex infrastructure, it still requires an intelligent synchronization server to synchronize the local and remote databases. Additionally, the system may need to add a mobile server to handle such administration functions as mobile user grouping, which facilitates user specific information processing. This technology is still in the early stages of development. Synchronization standards like SyncML appear to be in favor with some mobile computing experts; however, the industry is still in its infancy and there is no clear-cut predominant standard. Other disadvantages of the “offline” model include:

- The system is not “real time”. Critical information may not reach the mobile users or other stakeholders when needed.
- With regard to the WEN framework, “offline” database synchronization technology is not directly supported through the envisioned framework. The WEN framework is optimized for a wired “online” model.
- The mobile client device must be a more capable device in terms of memory and computing power to support “offline” operations.
- Mobile client software is more complex when compared to a browser based “online” client.

B. RECOMMENDATIONS

It is recommended that the next generation NALCOMIS system designers adopt the user centric paradigm and the UP design approach and expand on the products of Chapter III. Specifically, the maintenance technician and maintenance supervisor mobile aircraft maintenance office applications should be inducted into the inception phase of the UP process and ultimately integrated into the products developed in Chapter III. By doing so, next generation NALCOMIS users and developers can assess the viability of the total mobile aircraft maintenance office project. If the result of the inception phase determines the project warrants more investigation the project should move to the elaboration phase of the UP.

The “offline” models lower total ownership cost, reduced technological risk, and improved mobility makes it a more viable solution for the mobile aircraft maintenance office application. This type of application inserts the necessary hooks within the WEN

framework to facilitate extending other DoD e-business initiatives, that may not be well suited for the “online” model, to mobile business applications.

Lastly, designers should use commercially available mobile business development suites to develop and implement the mobile aircraft maintenance office application. Mobile computing technology is evolving at a rapid pace and choosing to develop the system internally from within DoD could leave users with a less than optimal system in terms in functionality, scalability, and interoperability. Products such as Sybase’s iAnywhere or Covigo’s Enterprise Mobility solutions offer a full suite of solutions that address the majority if not all of the major m-business development, implementation, and management issues identified in this research. This recommendation also includes commercially available mobile devices and operating systems. It is also important to emphasize open versus proprietary standards to ensure future flexibility and scalability. Organizations such as the Open Mobile Alliance²⁷ serve as a venue to sponsor open standards and interoperability. The alliance strives to focus industry efforts in the direction of mobile service standardization, interoperable services across countries, and to ensure operators and mobile devices meet user needs. Using commercially available hardware and software solutions that support open standards should lead to a less expensive system to develop, operate, and maintain and provide the necessary flexibility and scalability required to deal with rapid and sometimes disruptive changes in mobile technology.

C. FUTURE AREAS OF STUDY

The primary focus of this research was exploring the mobile computing technology landscape in order to generate the necessary artifacts to determine the project’s feasibility and functional requirements. As the project progresses into the elaboration phase, the need to explore specific areas related to the mobile technologies and its vulnerabilities make for excellent topics for future thesis research. The topics include:

²⁷ The Open Mobile Alliance formed in June 2002 with over 200 company’s representing the world’s leading mobile operators, device and network suppliers, information technology companies and content providers (Open Mobile Alliance Frequently Asked Questions, 2003).

- Explore the strengths and weaknesses of different database synchronization technologies as they apply to mobile applications.
- Identify the information security needs of mobile application and research suitable security mechanisms for the mobile devices and the data as it is transmitted over the air interface and public data networks.
- Perform an analysis of the information needs of fielded maintenance technicians and maintenance supervisors. Apply the results to properly match the correct mobile device to the specific user group's information needs.
- Evaluate different commercial vendor's mobile business development, implementation, and maintenance solutions to determine which best meets the mobile maintenance office requirements.
- Investigate the possibility of integrating the wide area mobile aircraft maintenance office application with a local area mobile application for flight line and hangar operations.

D. CONCLUDING COMMENTS

The concluding comments section centers on the strengths of adopting a user-centric approach, the UP system design methodology, and the importance of thorough technology review. The user centric paradigm and UP combination keeps the user at the forefront of all efforts and includes significant end user involvement throughout the development process. The UP and the employment of Use Cases provides a simple framework to quickly and easily develop a common vision, identify high level system goals and constraints, define the system's boundary, and develop scenario-based functional requirements. This effort in combination with a thorough technology review provides a foundation to adequately address other requirements and constraints to which the system must conform. It also provides the IT manager with tools to evaluate commercial vendor's products with regard to a well-thought out and engineered m-business initiative. Chapter III generated the first iteration of mobile project's vision, Use Case model, and supplementary specification and provides solid evidence that user focused design approaches are the right methodology required to properly engineer a mobile aircraft maintenance office application that has the best chance for implementation success.

APPENDIX A. CELLULAR TECHNOLOGY BACKGROUND

A. INTRODUCTION

Developments in modulation techniques and access methods combined with rapid advances in microchip technology made wireless telephony feasible for public consumption in the late 1970s. In the early 1990s analog cellular operators began the migration to digital modulation schemes in order to address the shortcomings of the first generation systems. The mid 1990's witnessed the unforeseen explosion in public Internet usage and marked the beginning of the Internet Age and the revolution in the way people and organizations communicate and conduct business. Within the last five years wireless technology has matured to the point it is no longer a fantasy to imagine a world where mobile users can access the information they need anytime and anywhere. Cellular technology has migrated from its humble beginnings as a circuit switched analog voice communications networks to more reliable and secure digital modulation systems. The migration is continuing and is currently introducing transitional technologies capable of simultaneous digital voice and packet switched data services. The ultimate goal of these new wireless cellular systems is to combine the Internet, telephones, and broadcast media into a single device via Third Generation (3G) Cellular networks.

Currently, the true meaning 3G is obscured by different marketing terms. Further complicating the issue is the fact the governing International Mobile Telecommunications-2000 (IMT-2000) specification recognizes five different network platforms as third generation systems. This appendix will detail the evolution of cellular industry and introduce the basic concepts and capabilities as they pertain to the different cellular networks leading to up to 3G. This historical foundation is necessary to better understand the problems and issues surrounding 3G implementations.

B. EVOLUTION OF CELLULAR TECHNOLOGY

1. The Humble Beginnings

Mobile telephony dates back to the 1920's when several police departments in the United States experimented with radiotelephony. The equipment was extremely bulky

and severely limited in channel capacity. These early experiments resulted in limited success with maritime vessels; however, proved not particularly well suited for land use, as radio technology did not deal well with buildings and other obstacles associated with metropolitan environments.

The development of frequency modulation (FM) in the 1930s enabled radiotelephony to network tactical units and their commanders on the battlefield during World War II. Wartime radiotelephony developments carried over to peacetime and the world saw limited mobile telephony service emerge in some large cities by the mid to late 1940's (Smith & Collins, 2002). The primary method used to provide mobile telephone service was similar to the methods used by broadcast radio and television. More simply stated, the systems relied on a single transmitter placed on top of a tall building and consisted of a finite number of channels. The limited channel capacity of these systems rendered them unviable for commercial applications. Radio access, modulation techniques, and microchip technology would have to evolve another thirty years before mobile telephones and the supporting radio networks would reach the level suitable for public acceptance.

2. First Generation Systems (1G)

Emerging in the late 1970's and earlier 80's in the United States, Japan, and Europe, mobile communications, as we know it today, finally became commercially feasible. Based on purely analog transmission techniques, these 1G technologies mark the genesis of the wireless network migration paths. The United States and Japan deployed Advanced Mobile Phone Service (AMPS) operating in the 800 MHz cellular band while the European's deployed Nordic Mobile Telephony (NMT), operating in the 450 MHz and later in the 900 MHz bands. In 1985, the British deployed a Total Access Communications System (TACS) also operating in the 900 MHz band. Smith and Collins (2002), describe TACS as nothing more than a modified version of AMPS. The Japanese later adopted a modified version of TACS calling their system J-TACS. AMPS, NMT and TACS are the predominant 1G systems and some are still in service today. Table 5 presents a summary of 1G analog cellular systems.

System	Frequencies (MHz)		Spectrum per Channel	Channel Size	Max Data Capacity	Countries Used in
	Downlink	Uplink				
AMPS	869-894	824-849	24 kHz	30 kHz	9.6 kbps	Americas
J-TACS	925-940	870-885	10 kHz	25 kHz	.3 kbps	Japan only
NMT	463-467.5 935-960	453-457.5 890-915	9.4 kHz	25 kHz	1.2 kbps	Scandinavia, Eastern Europe, Asia
TACS	935-950 917-933	890-905 872-888	19 kHz	25 kHz	8.0 kbps	Western Europe, Asia

Table 5. Analog Cellular System Summary.
(After: Dorman, 2001)

First generation cellular systems use analog transmission techniques in combination with Frequency Division Multiple Access (FDMA) schemes to increase the capacity of individual cells within the network. To support multiple simultaneous conversations within a cell, FDMA divides the available spectrum into sub channels. FDMA access method increases subscriber capacity for a given bandwidth when compared to earlier technologies; however, in the case of AMPS, requires a seven-cell cluster frequency reuse pattern. This reuse pattern maximizes capacity while minimizing interference from adjacent cell clusters. Frequency division multiple access' most significant shortcoming is that nearby frequencies interfere with each other and need to be separated by a gap or guard band which is considered an inefficient use of frequency spectrum (Dornan, 2001).

First generation systems experienced success far greater than anyone had expected. It was this unforeseen demand for mobile communication services that actually exposed 1G network capacity limits especially in heavily populated metropolitan areas. It was common in these areas for the number of users to exceeded individual cell capacity. Additionally, because the systems did not utilize digital transmission techniques their signals were extremely susceptible to variations caused by noise, which affected call quality (Tomasi, 2001). Furthermore, these systems were very insecure allowing snoopers to monitor conversations with a simple radio tuner and charge calls to an unsuspecting person's account. First generation systems were also incapable of sending digital data; however, it was possible to use modems directly with AMPS (Held, 2001).

Despite these shortcomings, Smith and Collins (2002) feel it was the introduction of first generation systems that began the wireless revolution toward mobile telecommunications being an accepted and expected method of communication. The shortcomings in 1G capacity, interference, security, and digital data incapability became the primary drivers for wireless research as engineers charted the migration path to the second generation of cellular technologies.

3. Second Generation Systems (2G)

In response to the inherent weaknesses associated with analog 1G systems, second generation (2G) systems employed digital transmission methods. These digital systems have a number of advantages, including greater capacity, increased security against fraud, encryption, and are capable of more advanced services such as simple text messaging, voice mail, and caller ID.

Second generation systems consist of various types of technologies. The three most successful systems deployed are Global System for Mobile communications (GSM), D-AMPS 1900, sometimes referred to as Interim Standard-136 (IS-136), and IS-95 referred to as cdmaOne. Dividing these three 2G platforms into two categories based on access technologies employed, Time Division Multiple Access (TDMA) or Code Division Multiple Access (CDMA), one sees the nexus of the diverging evolutionary paths toward 3G.

a. Time Division Multiplex Accessing Systems

Both D-AMPS 1900 and GSM employ TDMA technology to allow multiple users to occupy the same sub channel on a time-sharing basis. The resulting increase in the capacity of an individual cell is proportional to the number of time slots allotted per sub channel. D-AMPS 1900 divides each channel into six slots with each user requiring two time slots, whereas GSM subdivides each channel into eight slots, each supporting a single user. A TDMA platform that allocates seven time slots per channel realizes seven times more capacity within a cell over a 1G FDMA system. TDMA offers three other advantages. First, it reduces interference from other simultaneous transmission since users are separated by time. Secondly, it extends battery and talk time of the Mobile Terminal Set (MTS) since it is only transmitting during the assigned time

slot. Lastly, when a TDMA frame is both channelized and divided into sub channels, services such as paging and short messages become possible (Gil Held, 2001, p. 67).

b. Code Division Multiple Accessing Systems

CdmaOne uses CDMA technology. In CDMA there is no restriction on time or bandwidth in that the transmitter may transmit whenever it wishes and can use any or all the bandwidth allocated to the system or channel (Tomasi, 2001). CdmaOne takes advantage of spread spectrum technology and employs the Direct Sequence Spread Spectrum (DSSS) technique for the spreading function. CDMA neither divides the time nor frequency domains; instead, all CDMA users share the same frequency at the same time. It is obvious this technique causes all users to interfere with each other. Modulating each user's signal with a unique pseudonoise (PN) digital signal to spread the signal over a wide bandwidth overcomes this interference problem. The PN signal actually represents a code of chips, where chips refer to small data bits in the PN code. To illustrate the concept of chipping and how it artificially increases the data rate and bandwidth, assume three sub-bits, called chips, replace each bit of the original signal. The resulting multiplication process yields three chips for every original bit thus, increasing the data rate and bandwidth by three.

The PN code bit rate is significantly faster when compared to the bit rate of the original information. A replica of the PN code is available at the receiver, which allows the receiver to isolate the sequence of interest from all the other signals present, which appears as background noise. This technique enables a large number of CDMA signals to share the same frequency spectrum. Gil Held (2001) states,

Because frequency changes over time, CDMA can be considered to represent a combination of FDMA and TDMA. That is, transmission can commence at frequency f_1 for period t_1 , then move to f_2 for period t_2 , and so on" (p. 117).

Comparing CDMA to TDMA and FDMA, CDMA appears to require more bandwidth per channel than other technologies; however, the bandwidth is shared by many users simultaneously and thus uses the spectrum more efficiently (Dornan, 2001). Additionally, CDMA systems operate with a lower signal to noise ratio while maintaining a given channel capacity and benefit from increased cell and system

capacity. Furthermore, CDMA systems can use the entire available frequency spectrum and do not require frequency re-use patterns like TDMA systems.

Unlike that required by FDMA and TDMA platforms, CDMA systems eliminate the need for frequency reuse planning. CDMA cells overlap and contain handoff regions where the MTS may be connected to two different cellular base stations simultaneously. As the MTS transits from cell to cell in the CDMA network, the MTS experiences soft hand offs²⁸, or a “make before break” type of transfers from cell to cell. Soft handoffs improve reliability and results in dropped calls only if the user is moving extremely fast or physically passes outside the cellular boundary (Dornan, 2001). Soft handoffs also allow for pinpointing a user within the network through triangulation. Andy Dornan (2001) points out that soft handoff is proposed for most third generation systems, but the only one to use it so far is Qualcomm’s cdmaOne (IS-95) (p. 48).

Lastly, CDMA is the only wireless access technology that directly supports a TCP/IP-compliant stack. This capability permits the use of common IP protocol for the transportation of data over a wireless connection to the Internet, company intranets, and any computer using the TCP/IP protocol suite. This will be a key advantage in the development 3G high-speed data services.

c. Personal Communication Service (PCS)

The 2G systems of the 1990’s involved not only the migration of analog systems to digital system in the 800/900 MHz cellular band but also the introduction of Personal Communications Service (PCS) occupying the 1900 MHz band. For existing cellular operators, the migration path basically fell along two lines- TACS and AMPS spectrum. For operators employing the TACS spectrum allocation, GSM was the preferred migration path. The operator’s employing AMPS had a choice between TDMA (IS-54/IS-136) and CDMA (IS-95) radio access platforms (Smith & Collins, 2002). Europe implemented cellular and PCS networks based on the GSM digital standard while the United States deployed a mix of GSM, D-AMPS, and CDMA cellular and PCS

²⁸ Soft handoff refers to the radio link between the mobile device and the base station. A soft handoff ensures as a device moves from cell to cell, a link is established in the new cell before breaking the link in the previous cell.

systems. Japan deployed a modified a version of D-AMPS called Pacific Digital Cellular (PDC).

d. Data Capability

Second generation systems succeeded in their quest to improve on 1G systems in the areas of capacity, cellular fraud, security, and improved features. However, Smith and Collins (2002) indicate that 2G systems primarily focused on using digital techniques to enhance capacity over analog systems and their principal service was voice communications. 2G systems were capable of sending data, but usually were capable of less than 10 kbps best effort. To put 2G data capabilities into perspective, most modems achieve a real speed of 30 kbps (Dornan, 2001). Data characteristics for the three primary 2G systems are summarized in Table 6.

2G Technology	Data Capability	Spectrum Required /Channel	Number of Time Slots/Channel	Comment
GSM (TDMA)	9.6 kbps or 14.4 kbps	200 kHz	8	Circuit Switched data
D-AMPS 1900 IS-36 (TDMA)	9.6 kbps	30 kHz	6	Circuit Switched data
CDMA (IS-95A) /J-STD-008	9.6 kbps/14.4 kbps	1.25 MHz	N/A	Circuit Switched data

Table 6. 2G Data Capability.
(After: Smith & Collins, 2002)

It is important to realize 9.6 kbps was more than sufficient to meet mobile faxing requirements of the early to mid 1990s. In the United States, a separate mobile data system was deployed called Cellular Digital Packet Data (CDPD) and was designed to meet the mobile date requirements of the time. Cellular Digital Packet Data is a simple packet switched overlay to AMPS and D-AMPS (IS-54/136) cellular networks. The system's maximum capacity is 19.2 kbps (downlink) and 9.6 kbps (uplink) and uses a single channel in each cell for data; however, this capacity is shared between all users within the cell and makes actual throughput available to individual users much lower (Dornan, 2001).

The exponential growth of the Internet in combination with the mass proliferation mobile computing devices, such as notebook computers and PDAs, quickly

proved 2G data service rates to be inadequate to support modern applications. Researchers saw this need coming and began plotting a migration path to 3G wireless technologies via the IMT-2000 specification. Because of market risk, upgrade costs, and the requirement to be backwards compatible with existing 2G networks, operators would need to phase in new services outlined by the IMT-2000 specification for 3G systems. This resulted in development of 2.5 Generation (2.5G) transitional technologies to allow operators possessing cellular, PCS, or Universal Mobile Telecommunications System (UMTS) spectrum to deploy digital packet services prior to the availability of 3G platforms (Smith & Collins, 2002).

4. Two Point Five Generation Systems (2.5G)

Smith and Collins (2002) define 2.5G as “the method or methodology from which existing cellular and Personal Communications Service (PCS) operators are migrating to the next generation wireless technology referenced in the International Mobile Telecommunications-2000 (IMT-2000) specification” (p. 166). These 2.5G transitional technologies are primarily concerned with increasing data speeds above 2G’s meager 14.4 kbps to at least that of fast modems. The key 2.5G platforms are as follows:

- General Packet Radio Service (GPRS)
- Enhanced Data Rates for Global Evolution (EDGE)
- Code Division Multiple Access 2000 (CDMA2000 1xRTT)

a. General Packet Radio Service (GPRS)

GPRS systems provide packet data at higher speeds than those available over standard GSM circuit switched data services. Originally conceived as an upgrade for any TDMA-based system, GPRS has proved to effectively work with only GSM systems (Dornan, 2001). Utilizing the same 200 kHz channels and eight time slots per carrier allows the GPRS air interface to share GSM’s RF resources.

GPRS achieves greater speeds over the same basic GSM air interface through the use multiple time slots. Although never realized in operational networks, the GPRS air interface is capable of theoretical speeds up to 171 kbps. The practical maximum is 115.2 kbps, with realistic speeds of about 40 kbps or 53 kbps (Smith & Collins, 2002). The channel coding of GPRS is different than that of GSM and allows for

different data rates per time slot. GPRS networks using Coding Scheme 2 (CS-2), which allows for 13.4 kbps per time slot, can provide user rates of 40.2 kbps or 53 kbps assuming the subscriber has access to three or four time slots respectively.

GPRS's biggest advantage is that it employs packet switched technology. Unlike circuit switched systems where a connection is maintained regardless of whether data is being transmitted, the packet switched system consumes RF resources only at the instant that data is being sent or received. When a MTS is not sending data, another MTS set can use the time slots on the air interface. This procedure requires a request-allocation process between the MTS and the network whenever a user's MTS needs to send data. The user perceives the GPRS system as "always connected" to the network as the aforementioned procedure is transparent and happens quickly enough to appear "always-on" (Smith & Collins, 2002).

b. Enhanced Data Rates for Global Evolution (EDGE)

Originally, EDGE stood for "Enhance Data Rates for GSM Evolution"; however, shortly after being proposed, the technology received a recommendation suggesting it as a possible migration path for IS-36 TDMA network evolution too. This proposal precipitated the switch from "GSM" to "Global" in the acronym. Smith and Collins (2002) and Dornan (2001) both point out EDGE inherited almost all of its main features and network elements including interfaces, protocols, and access procedures from GPRS. The basic goal of EDGE is to complement GSM/GPRS networks in order to increase data throughput rates above that which is possible via GPRS alone.

Like GSM/GPRS, EDGE operates using the same 200 kHz, eight time slot TDMA channels; however, it uses Eight Phase Shift Keying (8-PSK) versus .3 Gaussian Minimum Shift Keying (GMSK) as the air interface modulation scheme. The advantage of this modulation change lies in the fact that 8-PSK offers approximately a 3:1 increase in bandwidth efficiency over the .3 GMSK scheme employed by GSM (Tomasi, 2001). Using the 8-PSK-air interface modulation scheme, EDGE networks theoretically support speeds up to 384 kbps. The increased bandwidth efficiency and resulting increase in throughput comes at the expense of additional hardware costs required to support 8-PSK

modulation, increased bit error rates due to 8-PSK's greater sensitivity to noise, and in smaller individual cell foot prints.

The Shosteck Group (2001) point out in a white paper that the deployment of EDGE by either a GSM or D-AMPS 1900 operator would be more than just a software upgrade. The paper suggests the EDGE upgrade may require additional hardware subsystems of cell sites, changes in frequency reuse patterns, and implies changes in base station antennas. Additionally, since the cell footprint associated with 8-PSK is smaller than for GMSK, more base stations may be required (Smith & Collins, 2002). Lastly, the user's MTS would have to support all three modes of operation - GSM, GPRS and EDGE. It is because of the above reasons, the Shosteck Group (2001) concludes, "For such reasons, the implementation of EDGE may be more complex than some may have initially envisioned" (p. 16). Smith & Collins (2002) support the Shosteck conclusion when they state, "It remains to be seen whether EDGE will be widely deployed as pseudo-3G system, as a stepping stone toward UMTS, or whether operators will decide to leapfrog EDGE and move directly from GPRS to UMTS" (p. 196).

c. Code Division Multiple Access2000 (CDMA2000 1xRTT)

The CDMA2000 One Times Radio Transmission Technology (1xRTT), referred to a phase one or (1X) of the 3G-migration path from cdmaOne to CDMA2000, is a predominantly non-European platform transitioning cdmaOne (IS-95 A/B) voice systems to high-speed packet data networks capable data rates of 144 kbps. This transition technology capitalizes on existing cdmaOne radio base stations and spectrum allocations and is fully backward compatible with the cdmaOne infrastructure and subscriber units (Smith & Collins, 2002). Additionally, phase one supports all of the cdmaOne's voice, circuit switched data, Short Message Service (SMS), and over the air provisioning and activation services. It also supports handoffs with cdmaOne systems and uses both common carriers as well as new carriers (Smith & Collins, 2002). CDMA2000 is backward compatible with existing 2G cdmaOne systems allowing for less expensive, phased oriented upgrades and changes from a fixed network perspective.

The CDMA2000 1X architecture is essentially the same as that used for IS-95 systems; however, still requires new components and upgrades to the existing 2G-

network. The upgrades include new element cards in the Base Station Transceiver (BTS) and Base Station Controllers (BSC) in combination with a few new data network components and improved vocoders to handle the packet switched data sessions. Phase one uses the same 1.25 MHz channel bandwidth as IS-95 systems. However, the upgraded system uses improved vocoders and 128 Walsh codes, as compared to sixty-four in cdmaOne, to achieve higher data rates and greater voice capacity (Smith & Collins, 2002).

CDMA2000 1xRTT is a logical migration path for cdmaOne operators just as GPRS and EDGE is for TDMA operators since each makes use of existing network infrastructure. However D-AMPS (IS-36) operators must make a choice either to go towards GSM/GPRS/EDGE route, proceed direct to Wideband-CDMA (W-CDMA), also referred to as UMTS, or switch to CDMA2000. Figure 4 summarizes the linkages between various platforms the migration path from 1G to 3G.

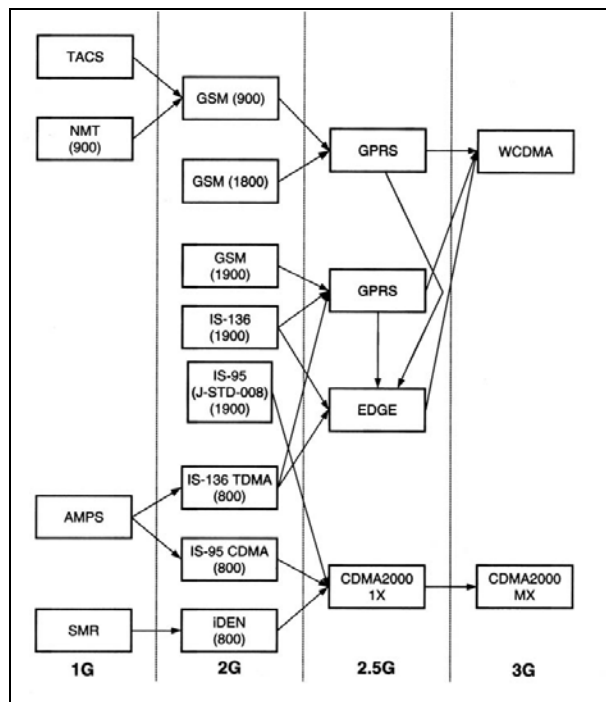


Figure 4. 3G Migration Paths of Various Platforms.
(From: Smith & Collins, 2002, p. 139)

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APPENDIX B. INTERNATIONAL MOBILE TELECOMMUNICATION-2000 STANDARD

A. THIRD GENERATION DEFINED

The dramatic growth in the wireless market due to the success of 2G digital cellular and PCS networks led to the demand for new features and more efficient services. In 1992, the ITU defined the standard for the UMTS system via the IMT-2000 specification. The specification calls for high-speed broadband data services, simultaneous voice and data capability, referred to as multimedia support, improved system efficiency to reduce costs, and backward compatibility with 2G systems. The IMT-2000 specification envisions UMTS as a universal or global service and requires the cooperation of many leading standard committees across the globe to develop such systems. Currently, the IMT-2000 standard organization is delegating the responsibility of 3G-platform development to two international partnerships: Third Generation Partnership Program (3GPP) and the Third Generation Partnership Program 2 (3GPP2). The 3GPP organization is responsible for coordinating the international effort for the W-CDMA standard based on backward compatibility with GSM and IS-136/PDC, while the 3GPP2 coordinates the CDMA2000 standard based on backward compatibility with the cdmaOne.

The primary focus of the IMT-2000 specification is to increase data rates of wireless networks. Originally, three different data rates were established, each corresponding to the B, H, and P-rate Integrated Services Digital Network (ISDN) lines for fixed carriers' core voice networks (Dornan, 2001, p. 102). More specifically, IMT-2000 specifies 3G networks shall be capable of 144 kbps, 384 kbps, and 2 Mbps for vehicular, pedestrian, and indoor fixed wireless applications respectively. The specification also includes variable data rates for large geographic coverage areas via satellite systems. As the Internet's popularity exploded in both the commercial and private markets, the ITU realized that "Surfing the Web" would become one of 3G's most important applications. Foreseeing the demand for the Web, the ITU added the additional requirement to the IMT-2000 specification mandating support for Internet

protocols and that 3G network backbones be packet switched. The change did not alter the above mentioned data rate requirement but did make the circuit switched ISDN concept obsolete.

The key goal of IMT-2000 specification is to combine the Internet, telephones, and broadcast media into single device. To do so, IMT-2000 systems must deliver six broad classes of services - interactive media, high multimedia, medium multimedia, switched data, simple messaging, and speech. Table 7 depicts the data rates, level of asymmetry, and switching modes for these six services.

Service Classification	Upstream Data Rate	Downstream Data Rate	Asymmetry Factor	Example	Switch
Interactive Multimedia	256 kbps	256 kbps	Symmetric	Videoconferencing	Circuit
High Multimedia	20 kbps	2 Mbps	100	Television	Packet
Medium Multimedia	19.2 kbps	768 kbps	40	Web Surfing	Packet
Switched Data	43.2 kbps	43.2 kbps	Symmetric	Fax	Circuit
Simple Messaging	28.8 kbps	28.8 kbps	Symmetric	Email	Packet
Speech	28.8 kbps	28.8 kbps	Symmetric	Telephony	Circuit

Table 7. Service Types Available Over IMT-2000 ²⁹
(From: Dornan, 2002, p.105)

Theodore Rappaport (2002) states,

3G systems promise unparalleled wireless access in ways that have never been possible before. Multi-megabit Internet access, communication using Voice over Internet Protocol (VoIP), voice activated calls, unparalleled network capacity, and ubiquitous “always on” access are just some of the advantages being touted by 3G developers (p. 34).

However, contrary to Rappaport’s statement, many critics point out how expected 3G services are over hyped by extremely optimistic marketers and have led to the somewhat disappointing performance reviews surrounding 3G network introduction.

²⁹ Virtual circuits will likely replace physical circuits where the table indicates circuit switching is required (Dornan, 2002).

B. IMT-2000 SPECTRUM

The IMT-2000 specification originally suggested a global spectrum centered about the 2000 MHz region in order facilitate global roaming especially if using the same IMT-2000 platform. Dornan (2001) explains that Europe and many Asian countries set aside the ITM-2000 spectrum, with China being the only country that followed ITU's recommendation exactly. Europeans and Japanese were using portions of the designated spectrum for cordless phones and GSM and America had already used the entire recommended spectrum for its PCS or fixed wireless system. The only part of the 3G recommended spectrum that is still available worldwide is that earmarked for 3G satellite services. Analysts doubt that the world will ever see satellites capable of mobile operations of 144 kbps since broadband satellites need much higher frequencies to be effective (Dornan, 2001). With above argument in place, Dornan (2001) notes that many industry leaders suggest releasing the Mobile Satellite Service (MSS) spectrum for Cellular IMT-2000. Figure 5 summarizes the spectrum allocation for 3G cellular and MSS in major world economies. Figure 5 summarizes the spectrum allocation for 3G cellular and MSS in major world economies.

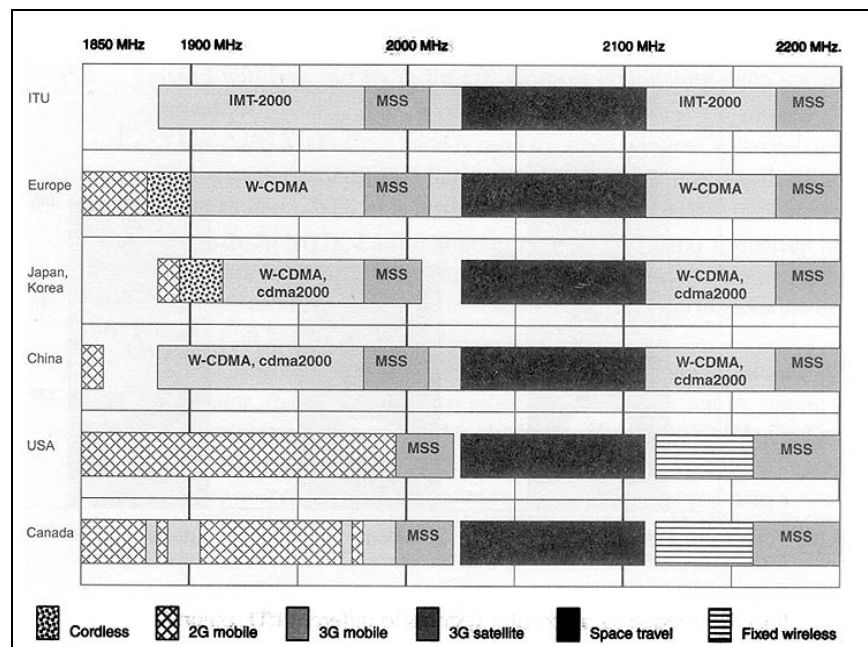


Figure 5. Spectrum Allocation for 3G Cellular and MSS in Major World Economies.
(From: Dornan, 2001, p. 107)

Currently, countries around the globe are attempting to identify new radio spectrum bands to accommodate the deployment of 3G networks expected in the 2004 - 2005 time frame. During its 2000 World Radio Conference, the ITU recommended the 2500-2690 MHz, 1710-1885 MHz, and 806-960 MHz bands as candidates for 3G. In the United States, spectrum in the upper UHF television bands near 700 MHz is being considered for 3G; however, given the economic slowdown of the television communications industry during 2001 many governments including the U.S. decided to postpone 3G auctions and spectrum decisions as of late 2001 (Rappaport, 2001). On July 23, 2002, the Federal Communication Commission, Department of Commerce, and Department of Defense agreed to release 90 MHz of spectrum for use by 3G services located between 1710-1755 MHz and 2110-2155 MHz. Third generation service providers can expect the new 90 MHz of spectrum to be available no later than 2008 (Department of Commerce, 2002).

C. SYSTEM INTER-COMPATIBILITY

Originally, the ITU envisioned UMTS as a brand new system. However, in 1996 this viewpoint changed allowing existing 2G networks to integrate with the UMTS services. Harte, Levine, and Kikta (2002) emphasize the significance of this change when they state, “This is very important as it allows existing wireless operators to cost effectively upgrade their systems and network equipment manufacturers to offer existing field-proven equipment to new operations without having to invest billions of dollars into research and new product development” (p. 21-22).

This change not only improved the cost feasibility of introducing 3G services, it facilitated the achievement of backward compatibility with existing 2G-system requirement. However, this change exacerbated the divergence in platform technologies as we move towards 3G and with the spectral issues mentioned above may lead to compromises in intersystem compatibility.

European and Japanese 3G deployment efforts focus on W-CDMA technology, as previously is also referred to as UMTS, while American and Korean efforts center around the CDMA2000 standards. It is important to note that North America has both cdmaOne

and GSM nationwide 2G systems; hence, U.S. wireless operators are deploying either W-CDMA or CDMA2000 systems based on their existing 2G-network platform access technology. Also adding to confusion is the divergence of 3G technologies as the IMT-2000 specification currently recognizes five different radio access platforms. Figure 6 depicts the different platforms comprising the IMT-2000 specification and their respective 2G access migration paths

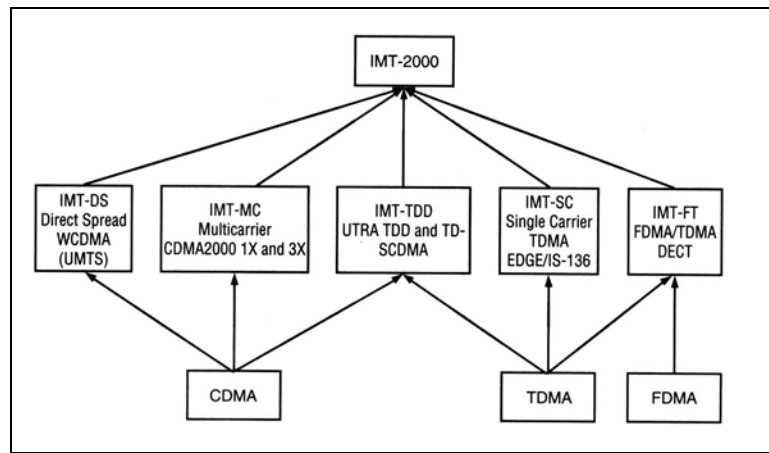


Figure 6. IMT-2000 Radio Access Platforms
(From: Smith & Collins, 2002, p. 137)

The above discussion concerning the various 3G migration paths and the IMT-2000 specification explains some of the confusion surrounding 3G systems and is supported by Smith and Collins (2002) when they state, “The radio access platforms that comprise the IMT-2000 specification are all different and it should be no wonder that is difficult to obtain a simple answer when asked to describe what a 3G system looks like” (p. 137). However, in 1999 a meeting of the International Telecommunications Union (ITU) group of radio experts endorsed harmonization for the CDMA component of the IMT-2000 standard. Gil Held (2001) explains, “The harmonization parameters for CDMA are structured to develop inexpensive multimode phones, which should enable W-CDMA and CDMA2000 phones to interoperate” (p. 141).

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APPENDIX C. THIRD GENERATION TECHNOLOGY OVERVIEW

A. INTRODUCTION

The two predominant system standards for third generation wireless systems are W-CDMA and CDMA-2000. Both technologies encompass Frequency Division Duplex (FDD) and Time Division Duplex (TDD) systems each optimized for a particular environment. W-CDMA is the most logical progression for GSM and IS-36 TDMA operators while CDMA2000 is the most logical for cdmaOne (IS-95) operators. The following discussion will focus primarily on the data aspects of the W-CDMA and CDMA2000 3G platforms as it pertains to theory, capacity, operation, and data rates.

1. Wideband Code Division Multiple Access (W-CDMA)

a. System Theory and Concepts

W-CDMA technology is a wideband spread spectrum technology that will replace GSM/IS-36/GPRS/EDGE 2.5G networks. Currently wireless operators in Europe, Japan and the United States are deploying or migrating towards the W-CDMA standard. The W-CDMA system utilizes paired 5 MHz FDD channels, efficient coding, and the capability to combine multiple traffic channels to provide low speed circuit switched and high-speed packet switched services. The standard employs direct sequence code division multiple access technology, Quadrature Modulation Phase Shift Keying (QPSK) modulation, and variable bandwidth control. Unlike the IS-95 CDMA systems described earlier, W-CDMA uses up to 256 (uplink) and 512 (downlink) spreading and channelization codes to vary bandwidth and achieve multiple channels within the same frequency band. W-CDMA can dynamically change its spreading codes to provide Bandwidth on Demand (BoD) services by changing the number of chips representing each bit of information.

A W-CDMA system uses a single type of radio channel to transfer voice, data, and control information. It does this by dividing the radio channel into overlapping physical and logical, also referred to as transport, channels. Unique channel codes identify the different physical channels while frame and field formats comprise the logical channels. A basic channel consists of 10 msec frames comprised of 15 times slot

bursts each lasting 666 usecs. Within a frame, a user is assigned one or more timeslots for reception and specific corresponding burst for transmission. It is important to note, that within a frame there are usually several time slots that remain idle. The MTS use the idle time slots to measure the signal strength of surrounding cell carrier channels. The idle listening assists in channel selection and handoff.

The FDD W-CDMA system uses two 5 MHz carriers- one for downlink or forward carrier (cell site to MTS) and one for uplink or reverse carrier (MTS to cell site). To simplify the design of the MTS, W-CDMA systems are not full duplex systems and do not transmit and receive at the same time. Harte, Levine, and Kikta (2002) explain that in order to emulate full duplex operations during voice conversations the system takes the compressed speech bursts and expands them in time to create a continuous audio signal.

W-CDMA uses several types of digital control channels in conjunction with digital traffic channels for each carrier. The digital control channels of W-CDMA are capable of coordinating multimedia, high-speed packet data, broadcast messaging, and fast power control and are considered superior to those of 2G GSM systems (Harte, Levine & Kikta, 2002). Unique spreading channelization codes allow control and traffic channels coexist on the same carrier frequency.

W-CDMA systems support asynchronous data transfer by incorporating variable spreading codes and time slot sharing. In theory, using different spreading factors, defined as the ratio of chip rate to the user data symbol rate, each down link and uplink channel is capable of 1920 kbps and 960 kbps respectively. However, in reality W-CDMA produces net data rates of up to 936 kbps for each downlink channel and up to 480 kbps for each uplink channel. The difference between the theoretical and net data rates is due to the addition of $\frac{1}{2}$ convolution coding error protection and overhead signaling information for downlink channel and error protection on the uplink channel (Harte, Levine & Kikta, 2002).

The modulation techniques employed by the downlink and uplink channels explains W-CDMA's asynchronous data rates. The downlink channel uses QPSK modulation, which generates one symbol for every two input bits whereas the

uplink channel uses dual channel modulation to produce one symbol for each input bit of information but one of the two channels supplies control information. Thus, for the same spreading factor one will observe approximately twice the data rate in downlink when compare to that of the uplink. Again, it is not exactly double due to the overhead signaling mentioned above. Table 8 shows the downlink and uplink data rates for the different spreading factors.

Spreading Factor	Theoretical Channel Rates (kbps) Downlink Channel/Uplink Channel	Net Data Rates (kbps)
4 (minimum)	1920/960	936/480
8	960/480	456/240
16	480/240	215/120
32	240/120	105/60
64	120/60	45/30
128	60/30	12/15
256	30/15	6/7.5
512	15 (Downlink only)	3

Table 8. Downlink / Uplink Channel Spreading and Data Rates.
(After: Harte, Levine & Kikta, 2002)

To achieve the data rates required by the IMT-2000 specification, W-CDMA combines up to three downlink physical channels in the same cell frequency. Using a minimum spreading factor of four and combining three downlink traffic channels results in theoretical data rate of 5.760 Mbps; however, with error coding and overhead the combination produces a net transmission rate of 2.3 Mbps (Harte, Levine & Kikta, 2002).

On the uplink side, W-CDMA combines up to six channels on the same cell frequency. Using the same spreading factor of four in combination with six traffic channels, W-CDMA provides theoretical data transmission rates of 5.760 Mbps and a net data rate of 2.8 Mbps. Unlike the downlink channel, uplink control and data information are sent on different channels so the uplink channel is not burdened with as much additional overhead.

It is important to note that W-CDMA is capable of speeds in excess of that required by IMT-2000. It is through a process called inverse multiplexing, that W-CDMA

combines multiple physical channel codes to achieve data rates in excess 2 Mbps. In essence, the system coordinates the data supplied to each channel and transmits a control message that identifies how the independent physical channels and their associated logical channels are combined or divided (Harte, Levine & Kikta, 2002, p. 301).

The mobility Quality of Service (QoS) requirement for 384 kbps at pedestrian speeds and 144 kbps at vehicular speeds are a function of the spreading factor required to maintain adequate error control. This BoD, suggests the faster the user is moving the greater the spreading factor, the greater the number of times a single bit is chipped to improve the gain, thus the lower data rates achievable.

It is important to understand that spreading factor is not the same as the channelization code; however, there is a correlation between them. The channelization code uniquely identifies each physical channel among other channels using the same frequency and does not alter amount of spreading of a given signal. However, channelization codes have a hierarchical structure where low level codes (high spread factors) are subsets of high level code (low spread factor) codes. This means that if a user has a demand for a high rate packet data session, requiring a minimum spread factor of 4 and thus requiring the highest level channel code, the lower level codes are not available. This essentially means that as the data requirements in a cell increase, the number of available channels decrease, thus limiting the cell's subscriber capacity.

b. System Architecture

The W-CDMA system includes many of the same basic subsystem components as the 2 and 2.5G wireless systems it replaced. Smith and Collins (2002) explain that W-CDMA borrows heavily from the established GSM/GPRS network architecture and reuses many of the components of the existing 2.5G systems. However, the Radio Access Network (RAN) portion, referred to as the UMTS Terrestrial Radio Access Network (UTRAN), of the W-CDMA system is significantly different from that of GSM, GPRS, or EDGE. This fact results in only limited reuse of existing GSM's Base Transceiver Station (BTS) and Base Station Controllers (BSC). Comparing W-CDMA to the CDMA2000 migration path costs, it is quite evident that W-CDMA is burdened with

greater migration implementation costs since it scraps TDMA as the access method. Figure 7 shows a basic block diagram of a W-CDMA network.

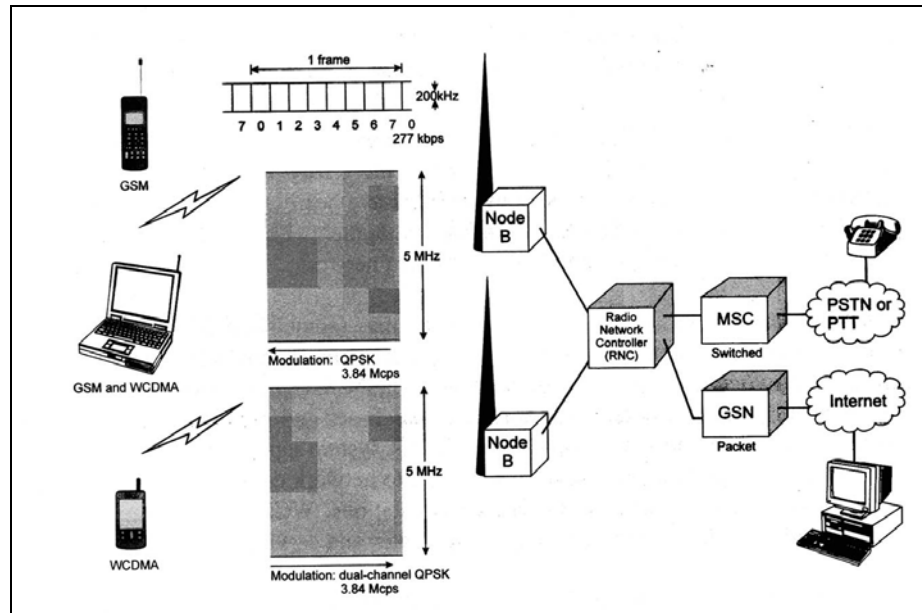


Figure 7. W-CDMA System Architecture.
(From: Harte, Levine, & Kikta, 2002, p. 268)

The W-CDMA network is broken in to three major parts: User Equipment (UE), UTRAN, and the core system network. The UE consist of various types of MTSS such cell phones, notebook computers, and wireless PDA devices. The UTRAN consists of multiple Node Bs and a RNC that function similarly to GSM BTSs and BSCs respectively. The circuit and packet switched systems, gateways, databases and system protocols comprise the core network. Figure 7 shows how the different parts interact to bridge the mobile user to the fixed public switched telephone network and the Internet.

The air interface is what connects the UE to the Node B. Each Node B, formally referred to as BTS in GSM, connects to a single RNC. The RNC controls the radio resources of the Node Bs connected to it and is analogous to the BSC in GSM. However, unlike the GSM radio access network where the BSCs are not connected to each other, W-CDMA systems incorporate an interface between the network RNCs to facilitate inter-RNC mobility and soft hand-offs between Node Bs connected to different

RNCs (Smith & Collins, 2002). The RNC connects to both the circuit switched and packet switched portion of the network via their respective interfaces.

The ultimate goal of W-CDMA is to completely converge voice and data services into a single packet switched network and is outlined in 3GPP Release 4 and 5 network architectures. The 3GPP Release 5 sees voice as simply a type of data with specific QoS requirements. Since this release is based on the use of Session Initiation Protocol (SIP) Smith and Collins (2002) state, “...the use of SIP means that a great deal of service control can be placed in the UE rather than the network, making it easier for the subscriber to customize their services to meet his or her particular needs” (p. 280).

The packet switched portion represented by GPRS Serving Node (GSN) box in figure 7 is comprised of both Serving GPRS Service Node (SGSN) and Gateway GPRS Serving Node components (GGSN). The SGSN performs UE status (e.g., idle or ready to receive data) monitoring, mobility management, security, and access control functions similar to its circuit switched counterpart the Mobile Switching Center (MSC).

The GGSN is the point of interface or gateway with external packet data networks (i.e., the Internet). If the GGSN supports Dynamic Host Configuration Protocol (DHCP) capabilities it assigns the UEs IP address, if not, it interfaces with DHCP server to obtain the required IP address and passes it to the UE. The GGSN maintains the anchor location information of the UE allowing the UE to migrate to different RNCs and SGSNs as it travels through the W-CDMA network. It also maintains a protected virtual tunnel from the external data network, using the GPRS Tunneling Protocol (GTP), through the SGSN to the RNC. The GGSN and the RNC add or remove the GTP wrapper at the terminal points of the GTP tunnel as data travels back and forth. The GGSN is also responsible for converting GTP data packets to TCP/IP packets and vice versa, enabling an interface to the Internet. But most notably, the GGSN hides the complexity of the W-CDMA network from the Internet. The GGSN appears like any other router on the network to other IP based machines, thus these external machines do not know the GGSN's users are mobile. IPoverATM provides the medium in which all data is transmitted via the packet switched segment of the W-CDMA network

c. Packet Data Transfer

W-CDMA provides a greater range of data speeds and flexibility when compared to the GPRS backbone deployed with GSM (Smith & Collins, 2002). The W-CDMA system, specifically the packet scheduler located in the RNC, allocates resources more efficiently than its 2.5G counterpart. Unlike the 2.5 GSM/GPRS network, the third generation system is capable of transmitting and receiving data on both common channels and dedicated channels. The choice of channel to be used is under the control of the RNC and is based on the type of session requested by the user- e.g., high volume streaming versus low volume bursty traffic. A description of the three types of transport channels used for packet data is listed below:

- **Common channels** usually carry signaling information; however, they can carry small quantities of packet data. This is a key improvement over the general radio packet service used by GSM, which could only send data over dedicated and shared channels.
- **Dedicated channel** can carry packet and circuit switched data. It is important to note, sending data over a dedicated channel, does require additional set up time; however, these channels have the capability for high speed data transmissions and soft handovers which are critical to uninterrupted data sessions in a mobile environment.
- **Shared channels** divide a channel up for use by several users by time division. These channels are well suited for short data packets. It is important to note the Common Packet Channel (CPCH) is similar to a shared channel in that several users share it by time division. There can be several CPCHs per cell site each having different bit rates.

The sending of data between the UE and the W-CDMA network involves packet access. The size of the data packets determines the type of channel the UE will request. For very small amounts of data or bursty type data, like a mouse click, the UE can use a common channel like the Random Access Channel (RACH) in the uplink or Forward Access Channel (FACH) in the downlink to transmit or receive the data. If the packets are a little larger, the UE can use a shared channel like CPCH. The UE requests a dedicated channel via RACH for large packet data services such as video streaming or large file transfers. Once the UE gains access to the dedicated channel, it transmits the packet over the air interface.

The serving RNC controls the handing off the UE involved in a given data session as it moves from one Node B to another. As previously mentioned, the GTP tunnel terminates at the RNC rather than the SGSN in the W-CDMA system. This means that when a user shifts from a group of cells controlled by particular RNC to a group of cells controlled by another, the original RNC may have to buffer packets until the UE relocation process has taken place. Once the relocation process is complete, the original serving RNC will relay the stored packets via the SGSN to the new serving RNC. In the case where the two RNCs connect to two different SGSNs, the transfer will be from RNC A to SGSN A to SGSN B to RNC B. This is a significant difference when compared to the 2.5G GSM/GPRS system deployed with GSM.

2. Code Division Multiple Access 2000 (CDMA2000)

a. System Theory and Concepts

CDMA2000 is the second most predominant migration path within the IMT-2000 specification and is an extension of the cdmaOne platform utilizing the IS-95/J-STD-008 standards. It is currently being developed and deployed in the United States, Canada, South Korea, India, Australia New Zealand, Russia, Romania, Israel, Moldova, Panama, Brazil, Columbia, Venezuela, Ecuador and Chile and is guided by the international 3GPP2 organization (3G Today, 2003).

Smith and Collins (2002) point out the CDMA2000 is unique in that, “while supporting 3G services and bandwidth requirements, it enables a logical migration from existing 2G platforms to 3G without fork lifting the legacy system” (p. 284). The cdmaOne systems are the only 2G platforms previously discussed that employ CDMA technology. This gives cdmaOne operators a significant cost advantage not enjoyed by GSM or other TDMA or FDMA access technology based competitors. First, existing CDMA networks only require a few new hardware components and upgrades to the existing core and air interface network. Dornan (2001) explains, “...most operators are able to upgrade their existing networks with new software or modulation rather than building a new radio system” (p. 113). This same advantage is not available to GSM/GPRS or IS-36 TDMA operators. CDMA2000 is backward compatible with all existing IS-95 systems.

The CDMA2000 standard is broken down in to two major categories- 1X (Phase one) and 3X (Phase two). The CDMA2000 standard migration path is as follows:

- CDMA2000 1xRTT
 - CDMA2000-1X (2.5 G)
 - 1xEV-DO (3G)
 - 1xEV-DV (3G)
- CDMA2000 3xRTT (3G)

Referring back to Figure 6 in Appendix B, one notes the Multi Carrier (MC) standard describing both the CDMA2000 1X and 3X platforms. This implies the use of more than one carrier; however, the CDMA2000 1xRTT utilizes a single 1.25MHz wide channel like its cdmaOne predecessor. The standards committees considered 1X as a MC system employing only a single carrier.

(1) CDMA2000 1xRTT. The three primary methods of CDMA2000 1xRTT technology are 1X, outlined in the 2.5 G section, One Times Evolution - Data Only (1xEV-DO), and One Times Evolution - Data and Voice (1xEV-DV). The later two methods represent the natural evolution for single channel high-speed data services that meet 3G specifications and are currently the most predominant players in the emerging 3G markets because of their lower implementation costs and the spectrum allocation issues explained earlier. These three methods are not mutually exclusive of each other and all utilize a single 1.25 MHz channel. To achieve greater data rates than 1X's 144 kbps (best effort) the 1xEV systems employ different modulation schemes, vocoders, and up to 128 Walsh codes.

CDMA2000 1xEV is an evolutionary advancement for CDMA originally pioneered by Qualcomm, Inc. as a proprietary high data rate (HDR) packet standard (Rappaport, 2002). Later, a modified HDR standard expanded compatibility from cdmaOne and 2000 systems to include W-CDMA. 1xEV-DO requires a separate carrier for data; however, if the user requires simultaneous voice and data services, the system is capable of handing off to a 1X carrier. By allocating a separate carrier for data, operators will be able to deliver peak rates in excess of 2.4 Mbps (best effort) to the user. Typical users may expect data rates on the order of several hundred kilobits per second

depending on the number of users, the propagation conditions, and vehicle speed. The expected throughput rates are still sufficient to support web browsing, email access, and m-commerce applications (Rappaport, 2002).

Adaptive rate operations allow 1xEV systems to achieve theoretical forward link data rates of 2.4 Mbps via a single 1.25 MHz channel. The base station rapidly adapts its data rate to each user by measuring the channel condition of each MTS via pilot signals. After determining the quality of each user's channel, the BTSs selects a suitable multi-level modulation format, either QPSK, 8-PSK and 16-Quadrature Amplitude Modulation (QAM) in order to deliver the highest data rate possible for the given channel condition. Eight-phase shift keying and 16 QAM provide three to four times more bandwidth efficiency when compared to IS-95's Binary Phase Shift Keying (BPSK) modulation. Additionally, 1xEV systems utilize a packet based time division-multiplexing scheme to improve available air resources and increase capacity on the forward link (Airvana, 2001).

The 1xEV system uses CDMA for its reverse channel and is capable of supporting data rates from 9.6 kbps to 153.5 kbps utilizing adaptive rate control. The BTS can control the data rate of the terminals, both individually and globally, and thereby increase total reverse link throughput while controlling interference (Airvana, 2001)

By 2004 or 2005, 1xEV-DV should become available for deployment (Carnese, 2001). 1xEV-DV will bring data and voice services for CDMA2000 back into one carrier. A 1xEV-DV carrier will provide not only high-speed data and voice simultaneously, but will also be capable of delivering real-time packet services.

(2) CDMA2000 3xRTT. CDMA2000 3X MC platform employs both wideband (reverse channel) and several narrow band channels (forward channel) in the process of achieving the required IMT-2000 data throughput rates. This is different from the 1X and W-CDMA platforms, which utilizes a direct spreading technique across a single 1.25 MHz or 5 MHz channel respectively. Multiple carrier technique spreads the data over the 1.25 MHz with a chipping rate of 1.28Mcps in a similar fashion as 1X and

W-CDMA; however, CDMA2000 3X positions multiple 1.25 MHz channels adjacent to each other to creating a wider channel capable of higher data transmission rates in the forward or downlink direction. The CDMA2000 3X standard combines three 1.25 MHz channels to form a 3.75 MHz channel with an equivalent chip rate of 3.684 Mcps ($1.28 \text{ Mcps} \times 3$). The system places a 625 kHz guard band on each side of the MC channel to buffer the channel from interference caused by adjacent cells. Total channel bandwidth for CDMA2000 3X is 5 MHz facilitating interoperability with W-CDMA systems. Figure 8 illustrates the difference between direct spreading and multiple carrier spreading techniques in addition to providing a comparison of the spectrum requirements of IS-95, CDMA2000-1X, and CDMA2000-3X platforms.

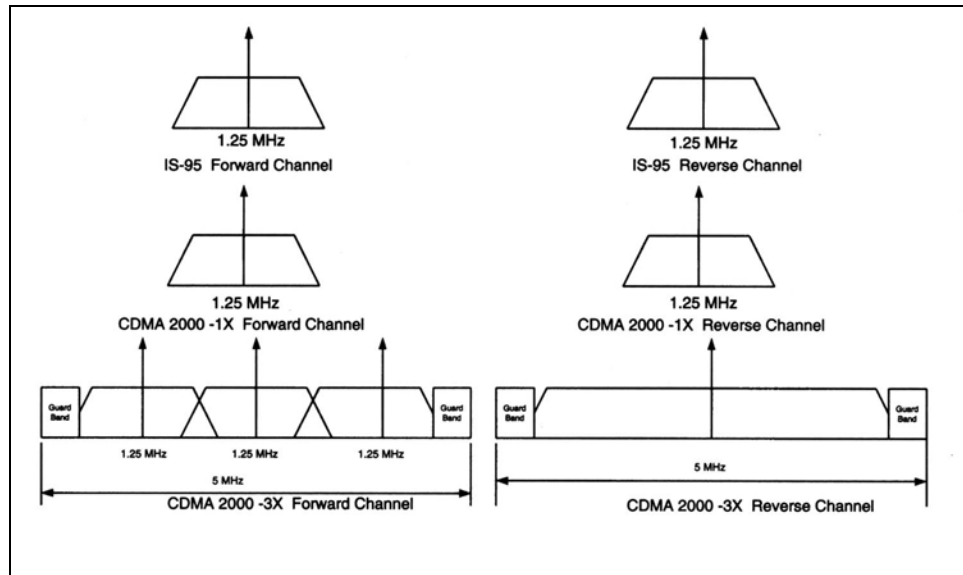


Figure 8. IS-95 & 1X Direct Spread and 3X MC Comparison

(From: Smith & Collins, 2002, p. 161)

Smith and Collins (2002) believe that IS-95, CDMA2000-1X and CDMA2000-3X will coexist in the same market and possibly within the same cell site. The migration path is dependent on the current system 2G system employed and the spectrum available or owned by the operator in addition to other critical dimensioning and cost factors that are beyond the scope of this research.

(3) Common Concepts of CDMA2000. CDMA2000 enhances the core capabilities of IS-95/J-STD-008 networks through modulation scheme changes,

newer vocoders, uplink pilot channels, expansion of Walsh codes and channel bandwidth changes. More specifically, CDMA2000 uses expanded Walsh codes (128 for phase one and 256 for phase two), QPSK (forward link) and Hybrid Phase Shift Keying (HPSK) (reverse link) modulation techniques, and improved vocoders to achieve the required data rates. Both CDMA2000 phases utilize new channel types for the radio access scheme and were required to support high-speed data in addition to some other functions such as paging.

A total of nine forward and six reverse link channels are defined for both CDMA20001X and 3X systems. The standard also describes two different Spreading Rates (SR-1 and SR-3) and nine different Radio Configurations (RC-1 through RC-9). CdmaOne and CDMA2000 1X implementations utilize SR-1, which has chip rate of 1.228 Mcps. CDMA2000 3X system are capable of using the SR-3 technique which produces a signal that has a chip rate of 3.6864 Mcps. However, it is important to note that SR-3 builds on the new coding implanted in SR-1 system but supports higher data rates.

The RCs incorporate different modulation, coding, and vocoders. Radio configuration one and RC-2 utilize BPSK modulation whereas RC-3 through RC-9 makes use of QPSK modulation. In addition to the different modulation schemes, RC-1 through 5 in the forward channel utilizes SR-1 and supports theoretical data rates of 230.4 kbps; the appropriate reverse channel also supports the same data rate. RCs six through nine in the forward channel utilize SR-3 and are capable of theoretical rate of 1.036 Mbps with same capability on the appropriate reverse channel. Lastly, the different radio configurations use different channel coding rates ranging from 1/2 to 1/6 rate and some use punctured channel coding to increase data transmission by up to fifty percent (Harte, Levine & Kikta, 2002). Tables 9 and 10 summarize the forward and reverse channel radio configurations.

Radio Configuration	Spreading Modulation	Spreading Rate	Chip Rate (Mcps)	Channel Coding	Data Rate (kbps)
1	BPSK	SR-1	1.228	1/2	1.2 – 9.6
2	BPSK	SR-1	1.228	1/2 punctured	1.8 – 14.4
3	QPSK	SR-1	1.228	1/4	1.5 – 153.6

Radio Configuration	Spreading Modulation	Spreading Rate	Chip Rate (Mcps)	Channel Coding	Data Rate (kbps)
4	QPSK	SR-1	1.228	1/2	1.5 - 307.2
5	QPSK	SR-1	1.228	1/4 punctured	1.8 - 230.4
6	QPSK	SR-3	3.684	1/6	1.5 - 307.2
7	QPSK	SR-3	3.684	1/3	1.5 - 614.4
8	QPSK	SR-3	3.684	1/4 or 1/3	1.8 - 460.8
9	QPSK	SR-3	3.684	1/2 or 1/3	1.8 - 1036.8

Table 9. Forward Channel Radio Configurations
(After: Smith & Collins, 2002)

Radio Configuration	Spreading Modulation	Spreading Rate	Chip Rate (Mcps)	Channel Coding	Data Rate (kbps)
1	BPSK	SR-1	1.228	1/3	1.2 - 9.6
2	BPSK	SR-1	1.228	1/2	1.8 - 14.4
3	QPSK	SR-1	1.228	1/4 or 1/2	1.2 - 307.2 (with 1/2)
4	QPSK	SR-1	1.228	1/4 punctured	1.8 - 307.2
5	QPSK	SR-3	3.684	1/4 or 1/2	1.8 - 614.4 (with 1/2)
6	QPSK	SR-3	3.684	1/4 or 1/2	1.8 - 1036.8 (with 1/2)

Table 10. Reverse Channel Radio Configurations
(After: Smith & Collins, 2002)

The CDMA2000 channel allocation is comprised of the forward link (base station to MTS) and reverse link (MTS to base station) and is similar to the uplink and down link terms used in the W-CDMA discussion. Regardless of whether discussing a 1X or 3X system, the uplink channel structure is the same. A Forward Fundamental Channel (F-FCH), Forward Supplemental Code Channel F-SCH (RC-1 and RC-2 only), Forward Supplemental Channels (for RC-3 through RC-9 combinations) and additional other common and dedicated channels comprise the forward traffic channel and are assigned to each CDMA2000 user.³⁰ The system assigns up to seven F-SCH (RC-1 and RC-2 only) channels for a given F-FCH. The forward supplemental channel only applies to RC3-9 utilizing QPSK spreading. The system can assign up to two Forward Supplemental Channels with a F-FCH.

³⁰ Note, only the F-SCH and Forward Supplemental Channel are for data.

CDMA2000 reverse link structure is similar to that of the forward link; however, it is important to note that the reverse channel for 3X is a direct spread over the 3.75 MHz and is not a multi-carrier distributed. Despite this difference, Smith and Collins (2002) indicate that the 3X structure can be overlaid on a 1X implementation. Similar to the forward link, the reverse link consists of a Reverse Fundamental Channel (R-FCH) for voice and Reverse Supplemental Code (R-SCH) and Reverse Supplemental Channels for data. The system assigns up to seven R-SCH (RC-1 and RC-2 only) channels with a given R-FCH. Like the forward channel, the system can assign up to two Reverse Supplemental Channels with a fundamental channel.

As previously mentioned, CDMA2000 increases the number of Walsh codes from 64 codes to 128 and 256 for CDMA2000 1X and 3X networks respectively. The introduction of QPSK channel spreading enabled the increase to 128 Walsh codes. CDMA2000 3X doubles the number of Walsh codes from 128 to 256 by using quasi-orthogonal masking functions (Hart, Levine & Kikta, 2002). Additionally, CDMA2000 ushers in the use of variable length Walsh codes, ranging from 2 to 256, to accommodate fast packet rates and allow for variable bandwidth (Hart, Levine & Kikta, 2002). Smith and Collins (2002) point out that the variable length Walsh code can impact the number of users in a given cell because orthogonality must be maintained. To explain, higher data rates require shorter Walsh codes in order to maintain the same spreading rates. The shorter Walsh code equates to fewer codes available to share across the channel, thus fewer simultaneous users. This limitation implies that the type of data transmitted over the network, such as video, can directly impact the number of users that can access a particular cell and requires network engineers to design a CDMA2000 network based on expected voice and data traffic. This limitation is similar to that explained in the W-CDMA channelization code discussion. However, engineers can employ a dedicated single channel for packet data only in areas where heavy data services are forecasted thus preserving voice platform availability and required data throughput (Smith & Collins, 2002).

b. System Architecture

Whether discussing a CDMA 1X or 3X system, both require relatively minor upgrades to the existing cdmaOne radio and core network. It is possible to migrate

cdmaOne systems all the way to 3X capability with no additional RF equipment and only software and baseband hardware changes (Rappaport, 2002). When compared to the migration path for W-CDMA, many advocates of CDMA2000 claim the standard provides operators with a more seamless and less expensive upgrade path since CDMA2000 allows the same spectrum, bandwidth, RF equipment, and air interface framework to be used at each base station as the 3G upgrades are introduced over time.

Figure 9 shows a simple block diagram of a CDMA2000 implementation identifying the upgraded and new components required to support IP packet services. Module additions or swaps comprise the upgrades to existing cdmaOne BTSs and BSCs. Components that are new to the system make up the packet switched data segment of the CDMA2000 network. These new components include a Packet Data Serving Node (PDSN), Authentication, Authorization and Accounting (AAA), Home Agent (HA), Routers, and a Firewall.

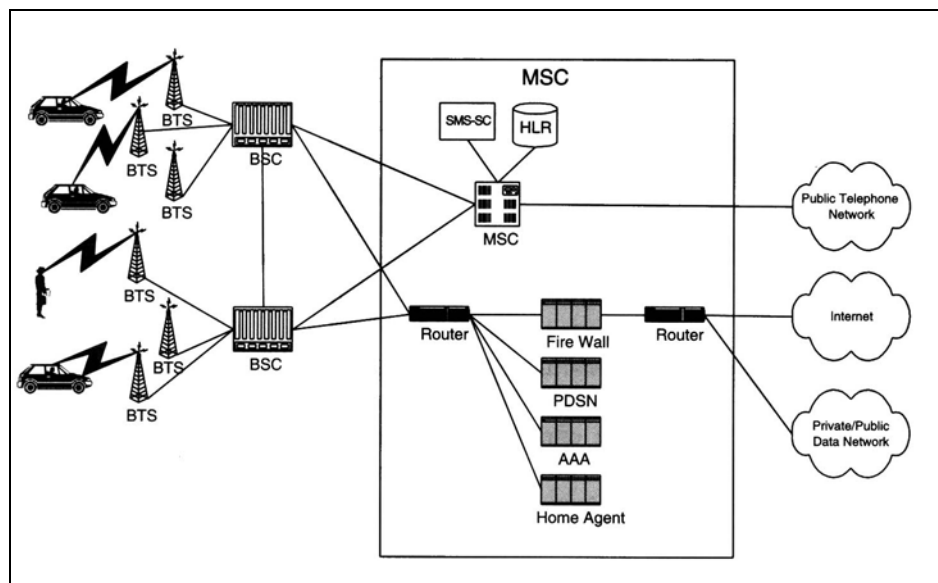


Figure 9. CDMA2000 System Architecture
(From: Smith & Collins, 2002, p. 288)

The MTS, Radio Network (RN), and the core network make up the CDMA2000 network architecture. Figure 9 shows how each component of the network interacts to connect the user to fixed public telephone, Internet, and private networks. The

CDMA2000 network segregates the circuit switched portion from the packet switched as the traffic leaves the RN usually at the BSCs in a similar fashion as W-CDMA.

The PDSN is at the core of the CDMA2000 packet switched network and is supported by Smith and Collins (2002) when they state, “the PDSN is the heart of the packet data services for a CDMA2000 network” (p. 288). The PDSN is responsible for supporting packet data services and performs seven major functions in the course of a packet data session. The seven major functions are as follows:

- Initiates, maintains, and terminates Point to Point Protocol (PPP) sessions with the MTS
- Supports both Simple and Mobile IP packet services
- Establishes and maintains the logical links to the radio network across the radio packet interface
- Initiates AAA for the mobile station client to the AAA server
- Receives service parameters for the mobile client from the AAA server
- Routes packets to and from external public and private data networks
- Collects usage data that is relayed to the AAA server

Another new component to the system is the AAA server. It is clear by its name that AAA is responsible for authenticating, authorization, and accounting functions for the packet data network portion of the CDMA2000 network. The AAA communicates with the PDSN via IP and performs the authentication associated with PPP and mobile IP connections. Additionally, the AAA checks the subscriber’s service profile and is responsible for security key distribution and management in its authorization capacity and of course keeps track of accounting with respect to data services for billing purposes.

A HA joins the network and is normally compliant with the Wireless IP Network Standard (IS-835). The HA performs a myriad of tasks and is specifically responsible for tracking the location of the mobile IP user as it moves through the CDMA2000 network. This function ensures the proper delivery of the packets to the MTS as it migrates through the network.

The routers that are involved in the CDMA2000 network are responsible for routing IP traffic to and from various core network elements within the CDMA2000.

They are also responsible for routing traffic to and from the internal network to both external public and private IP networks. The firewall is required to ensure security when accessing external data applications.

Additional subscriber information associated with the introduction of packet data services, which includes subscriber packet data service options, MTS capabilities, and voice platform needs are stored in the upgraded Home Location Register (HLR). The Visitor Location Register (VLR) pulls this data to the associated network as a result of a successful subscriber registration process.

The radio network upgrades include additional element cards to the BTS. The BTS controls the air interface between the CDMA2000 network and the MTS. The BTS is responsible for allocating radio resources (multiple carriers), forward power required for traffic overhead and soft handoffs, and Walsh code assignment. The BTS decides how best to distribute its resources based on the service requested, the RC, the subscriber type, and whether the service requested is voice or packet.

The BSC is responsible for controlling all the BTSs under its purview. Referring back to Figure 9, one sees the BSC routes packets to and from the BTSs and the PDSN. Also, it is responsible for routing time domain modulated traffic to the circuit switched network.

c. Packet Data Transfer

Data traffic can flow either over the circuit or the packet switched network. If the data travels over the circuit switched it is handled the same as voice traffic. But as mentioned above, all packet data calls must go via the PDSN that essentially serves as the interface between the air interface data transport and the fixed network transport. There are three packet data service states: active/connected, dormant, and null/inactive. When packet data is bi-directionally flowing between the MTS and BTS over a physical channel an active/connected condition exists. In a dormant state, no physical traffic channel exists but there is a PPP link between the MTS and the PDSN. For a null/inactive state neither a traffic channel nor PPP is maintained or established.

The MTS initiates voice, packet, or concurrent voice and data sessions. The PDSN does not communicate to the HLR or VLR to obtain the necessary subscriber information; instead, it communicates with AAA server. If the session involves data, the PDSN is designed to provide several key packet data services including Simple IP and Mobil IP and is capable of establishing Virtual Private Network (VPN) services with either Simple or Mobile IP.

Simple IP is where the subscriber is assigned static IP address using Dynamic Host Configuration Protocol (DHCP) services from the serving PDSN with its routing service provided by the local network. The MTS in an active or dormant state is free to roam from cell to cell within a network providing it does not enter a cell served by a different PDSN. Moving into a cell serviced by a different PDSN will result in the termination of the data session. When this happens the subscriber negotiates for another IP address from the new PDSN and must reinitiate the session. Simple IP is an origination-based service because it fails to provide for mobile termination (Smith & Collins 2002). More specifically, Simple IP is a PPP service using DHCP.

In Mobile IP, the public IP network provides the MTS IP routing service. The MTS is assigned a static IP by the PDSN and is stored in the HA. The establishment of the static IP address facilitates roaming during packet sessions, assuming the IP address scheme is unique enough for the MTS to be distinctively identified (Smith & Collins, 2002). Mobile IP overcomes the Simple IP roaming limitation via the HA and the assignment of a Care of Addresses (COA).

As the MTS enters a new cell served by a different PDSN, that PDSN acts as the Foreign Agent (FA) and the home agent, located in the home network, is setup as a virtual HA. The MTS registers each time it begins a packet data session, regardless of whether it originating or terminating the session. An IP-in-IP tunnel is established between the HA and the FA and is used to deliver IP traffic to the visiting network PDSN (FA).

When roaming, the MTS is responsible for informing the CDMA2000 network it has moved to another service. Once this has occurred, the MTS registers with

another FA, who then assigns the MTS a Care of Address (COA) which is sent to the HA. However, the MTS still retains the original static IP address. The home agent forwards the packets to the visited network via an IP-in-IP tunnel for delivery to the MTS by encapsulating the original IP packet with the COA. The packet arrives at the FA where it removes the COA wrapper and forwards the original packet, with the original static IP address, to the MTS. The MTS retains its static IP address the entire time, thus facilitating TCP's ability to maintain a proper connection.

In the reverse direction, the routing of IP packet occurs the same as if the MTS is on the home network and does not require an IP-in-IP tunnel. However, Dornan (2002) explains this Mobile IP process leads to problems when sending data to another network. He points out that every packet includes the sender's IP address, which for the mobile user may not match the network they are actually in. Many firewalls see this inconsistency as a spoofing attempt from a hacker and results in the packet being rejected.

Two other variants of Simple IP and Mobile IP supported by the PDSN include using of VPN technology. This enhancement allows for higher security and also provides connectivity to corporate local area networks and intranets. The system is able to provide this service using VPN tunneling protocols between the private network and the PDSN. Since VPN's essentially connect the mobile client to the companies LAN as if it were a part of it, the private network is responsible for assigning the MTS's IP address.

B. SUMMARY

Reviewing Appendices A, B, and C, one can more clearly see how and why the cellular operator's pursuit of IMT-2000 and 3G services can take various paths. Factors such as existing 2G infrastructure, available spectrum, and market expectations all play a major role in the cellular operator's decisions to implement a particular 2.5G and subsequent 3G platforms. As of January 2003, only four countries, Japan, South Korea, Austria and the United States have deployed true 3G platforms (3G is Here Today – 3G Operators, 2003). Japan's DoCoMo debuted their Freedom of Mobile Access (FOMA) W-CDMA 3G network in spring 2001 and rolled out services to the general public in the

Tokyo area that autumn. This action made Japan the first country to introduce 3G services. On 4 December 2001, Manx Telecom switched on Europe's first 3G W-CDMA systems on the Isle of Man located between Great Britain and Ireland. Two operators in South Korea successfully launched CDMA2000 1xEV-DO 3G services in the first half of 2002.

Based on the Asian market, industry experts feel CDMA2000 1X operators are currently in the best position thanks to lower cost for network upgrades, better capacity and speed, and affordable and attractive handsets (Carvalho & Shuper, 2002). In their report Carvalho and Shuper (2002), estimate that Sprint PCS would incur a \$1.6 billion dollar cost to reach CDMA1xEV-DO while AT&T Wireless would have to spend nearly three times that amount to upgrade to W-CDMA. It appears that both the higher cost for W-CDMA network upgrades and delays in handset availability is hindering W-CDMA deployment. Despite these short-term problems, experts believe in the long run the cost advantages of W-CDMA can be significant as they expect seventy-five percent of subscribers globally to ultimately migrate from GSM to W-CDMA (Carvalho & Shuper, 2002). The same experts believe W-CDMA phones will need extra RF chipsets to work with the new W-CDMA frequency in Europe and require more transistors to support backward compatibility with GSM. It is because of the added costs of these additional chipsets that one questions whether the aforementioned W-CDMA scale advantage will materialize. The same is not true for CDMA2000 phones.

As of this writing, Western Europe is mostly deploying GSM/GPRS 2.5G platforms while U.S. operators are rolling out a mix of GSM/GPRS and CDMA-1X 2.5 G services. It is likely that, since GSM operators possess sixty percent of the market share as compared to IS-95's twelve percent, W-CDMA will be the most predominant 3G platform deployed despite its slower and more costly introduction (Harte, Levine & Kikta, 2002). But to the global roamer it is important to remember that the IMT-2000 envisions global roaming between these two most predominant systems through the use of multimode smart phones and MTSs capable of W-CDMA and CDMA2000 operations.

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