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The DORIC Program: Integrated Tactical Radio Network Design Issues

S. Jayasinghe and D. Floreani

DEPARTMENT OF DEFENCE

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ABSTRACT

The report describes some of the issues involved in the design of integrated radio networks. The performance limits that arise when ATM is used are examined. Gateway design is discussed in terms of their functionality and protocol architectures.

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EXECUTIVE SUMMARY

The goal of the DORIC program is to design and develop an integrated communications architecture for the Australian Defence Organisation. From a networking point of view this would entail the integration of both the wired and wireless components of the composite architecture. The wireless component itself may consist of satellite networks and radio networks operating on different bearer channels. The design of the radio networks involves many issues that interact in a complex fashion, and they will exhibit different characteristics that depend on the initial design choices. So, it is informative to obtain an understanding of the important issues involved in the design of integrated Tactical Packet Radio Networks (TPRNs). To this end, four main issues are discussed, these being the topology of the network, its frequency of operation, channel access and routing.

Having an integrated communications architecture also implies using, as far as military requirements permit, the civil telecommunications infrastructure. The future of civil telecommunications is expected to revolve around the Broadband Integrated Services Digital Network (BISDN), which uses the Asynchronous Transfer Mode (ATM) protocol as its transport mechanism. For interoperability reasons, it is convenient to use ATM, or a closely related protocol, in the TPRN. This, however, is not straightforward since ATM was originally conceived for networks with high bandwidths and low error rates, quite unlike most TPRNs. There are performance limits to consider. For example, in HF radio networks with low throughputs, the packetisation delay, which is a component of the end-to-end delay, is large enough to adversely affect the transmission of real time services such as speech. Two performance limits, the end-to-end delay and cell loss, are discussed in the report.

The interfacing between a TPRN and BISDN is done via a gateway, which is a device that ensures seamless integration between two dissimilar networks. A gateway could

be deployed as a normal TPRN node with added functionality, or a dedicated device. The important functions that are required of a gateway are mapping of user services and signalling protocols, and routing calls between networks. The mapping of user services is necessary due to the differences in throughput in the two networks. The gateway may also use the most convenient media to connect to BISDN and as such, the design of the gateway should reflect media independence. The final two sections of this report discuss gateways, their functionality, and design in terms of the protocol architectures.

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1. Introduction

The goal of the DORIC program is to design and develop an integrated communications architecture for the Australian Defence Organisation. From a networking point of view this would entail the integration of both the wired and wireless components of the composite architecture. The wireless component itself may consist of satellite networks and radio networks operating on different bearer channels. The design of the radio networks involves many issues that interact in a complex fashion, and they will exhibit different characteristics that depend on the initial design choices. So, it is informative to obtain an understanding of the important issues involved in the design of integrated Tactical Packet Radio Networks (TPRNs).

Another dimension to integration is the extent to which Defence may use the civil telecommunications infrastructure. The future of civil telecommunications is expected to revolve around the broadband integrated services digital network (BISDN). The mechanism for the transport of information in BISDN is the Asynchronous Transfer Mode (ATM), a standardised multiplexing and switching technology. Although originally designed for high speed networks, ATM is very flexible in that a range of bit rates from zero upwards can, in theory, be accommodated efficiently. ATM can also be employed in different operating environments, from wide area networks to local wireless networks. This suggests that it may be possible to use ATM (or a closely related protocol) in the radio networks that constitute the wireless component of the defence communications architecture, thereby satisfying interoperability requirements with the civil networks. To this end, the report examines performance limits associated with using ATM in radio networks, especially high frequency (HF) networks.

If pure ATM were to be used in the radio network, this would mean the packetisation of the data into cells of 53 bytes and the preservation of the header fields as defined for use in the BISDN. However, this could lead to very inefficient operation, since the ATM cell structure may not be suited for use in the particular radio network that is being considered. So, it may be necessary to use a modified ATM cell in the radio network. This infers that there should be some sort of mapping that is performed at the interface between BISDN and the TPRN. This mapping is performed by a device called a gateway. Gateway design is an important part of the design of a TPRN and the report examines the functions of gateways and describes a suitable protocol architecture.

2. Aim

This report aims to identify some of the issues involved in the design of integrated tactical packet radio networks. In the interests of interoperability with future civil telecommunication networks, these TPRNs need to interface with BISDN, which uses ATM as its transport mechanism. The report also examines some performance limits associated with the use of ATM over TPRNs. Finally, the report examines gateway design. The functions that need to be performed by a gateway are discussed, and a suitable protocol architecture is proposed.

3. Radio network design

The radio networks considered here are those where packet switching is applied to radio channels. These packet radio networks operate by transferring information in the form of self contained units called packets (or cells in ATM terminology), which contain control and user data. The use of radio channels to convey the information has many advantages, the most significant being the ease with which mobile users may be accommodated. The disadvantage is the potential for interference between packets intended for different destinations.

3.1 Topology

The topology of a TPRN describes the number and density of its nodes, the function of the nodes, and the connectivity between nodes. The sophistication of the protocols employed determine the potential number of nodes that a TPRN can handle. Furthermore, as the number of nodes increase, so does the control traffic. This necessitates a higher network capacity, or, for the same network capacity, a reduction in the volume of allowable data traffic. So, a given TPRN must have a limit on the number of nodes that it can support.

Every node in the TPRN may not be identical in its function. Most nodes will be user terminals that are used to send, receive and store and forward data. However, there may be some nodes which are repeaters, some which are control stations, and still others which are gateways. Gateways are discussed in greater detail later. Repeaters may be necessary depending on the frequency of operation. Control stations are used to ascertain link connectivity, calculate the best routes from the source to the destination, and perform whatever other operations that are necessary to manage the network. A network with centralised control will typically have a single control station. The advantage here is that the control station, which is normally a fixed node, can be as complex and as powerful as necessary to serve the TPRN. This is because there are no constraints on size and power consumption. However, a major disadvantage is that the network becomes vulnerable to an attack on the control station. Having distributed control increases the reliability of the network, since it is no longer dependent on the operation of a single node.

Perhaps a suitable compromise could be to have a limited set of control stations. This lends itself to the idea of a hierarchical network [1]. In a hierarchical network the nodes are organised into clusters. Each cluster is a set of nodes which are within radio range of each other. Of course, certain nodes may belong to more than one cluster. Every cluster has a clusterhead, which is a control station for that particular cluster. Different clusterheads combine to form a super cluster, and so on, thereby giving the network a hierarchical nature. In networks with a large number of nodes, having a hierarchical structure reduces the volume of control traffic. However, specialised routing algorithms need to be designed to accommodate the hierarchical structure.

3.2 Frequency of operation

There are many factors to consider when determining a frequency of operation for the TPRN. Area coverage is a key factor. Greater distances can be covered with fewer nodes if relatively lower frequencies (eg. HF) are used. The higher frequencies require that nodes are within line-of-sight for successful transmissions, and this may necessitate the use of many repeaters, thereby increasing the effective number of nodes in the TPRN.

A redeeming factor in using higher frequencies is that it generally infers wider channel bandwidths and therefore higher data rates. This capacity increase is to be welcomed since it will facilitate the provision of multimedia services. The nature of the channel impairments also change with changes in frequency. For example, the delay spread caused by multipath propagation is in the order of milliseconds at HF and microseconds at UHF.

In determining a suitable channel bandwidth, an important issue is whether spread spectrum signalling is to be considered. Although requiring a greater bandwidth for a given data rate, spread spectrum signalling offers many advantages [2-3]. From a military perspective, it offers resistance to jamming and is difficult to intercept. Furthermore it offers capture and multiple access capabilities. Capture refers to the ability of a given receiver to demodulate a single packet in the presence of two or more packets that are addressed to it. This demodulation is done on the basis of time of arrival so that the first signal is captured and the others treated as noise. Multiple access refers to the ability of a receiver to receive a packet correctly when it is interfered with another packet intended for a different destination. This reception is possible because the two packets contain different spreading codes, thereby making the receiver immune to collisions.

3.3 Channel access

When a number of nodes share a single radio channel, there must be some rules governing the right to access the channel in order to transmit a packet. Else there would be collisions and confusion would result with the information being lost. This set of rules is called the channel access protocol, or, multiple access protocol. There are many multiple access protocols published in the literature [4] that are suited to particular environments and types of traffic. These protocols may be classified according to the way in which the channel is assigned, the two extremes being fixed assignment and no assignment (random access). In general, fixed assignment schemes are wasteful of bandwidth, by virtue of the fact that the channel may be allocated to a particular node even when that node has no data to transmit. There are three main random access protocols that are worthy of consideration for use in a TPRN, and these are discussed below.

The simplest random access scheme that may be used in a TPRN is pure Aloha. In this scheme, a user transmits a packet whenever one is generated. There is no coordination among the nodes in the network. If the packet is received successfully at the destination, an acknowledgment is sent back to the user. If a node does not receive an acknowledgment within a reasonable time-out period, it deems that a collision has occurred. In this event, the node waits a random time and retransmits the packet. It has been shown [5] that the throughput of Aloha in a fully connected network (that is, a network where all nodes can hear each other) is 18%.

This throughput can be doubled if a scheme known as slotted Aloha is used. In this scheme, time is considered to be slotted, and users can transmit a packet only at the beginning of a slot boundary. This reduces the vulnerable period (that is, the period in which a packet may collide with another) by half, and therefore doubles the throughput to 36%. However, slotted Aloha requires time synchronisation. This is a difficult task, especially in multihop networks. Furthermore, in networks with mobile terminals, time synchronisation may not be possible due to the varying propagation delays.

In both Aloha protocols, packet transmissions take place independently of activity in the channel itself, that is, the decision taken by a node to transmit is independent of the state of other nodes. This is one of the reasons for the high rate of collisions that occur in Aloha channels. It is intuitively obvious that collisions may be reduced if nodes considered the state of other nodes before transmitting. This is exactly what is done in a class of protocols known as carrier sense multiple access (CSMA). When a node has a packet to transmit, it first senses the channel for carriers due to other nodes' transmissions. If the channel is free, the node transmits. The action taken when the channel is busy depends on the variant of CSMA that is in use. This action may range from persisting with sensing the channel until it becomes free and then transmitting, to rescheduling sensing according to some delay distribution.

The performance of CSMA is dependent on the ratio of the propagation delay to the packet transmission time, the lower the ratio, the better being the performance. The throughput in CSMA can reach up to 90%, but this rapidly degrades with increasing values of the above mentioned ratio. Furthermore, CSMA does not perform very well in multihop networks due to the existence of `hidden' nodes, that is, nodes that are outside the range of the transmitting node. So, the choice of a multiple access protocols depends on the topology of the network.

3.4 Routing

The design of routing algorithms for TPRNs should take into account the particular features of these networks, most importantly, the topological changes that occur due to nodal mobility. Furthermore, link connectivity could be affected by natural phenomena such as fading, or deliberate interference such as jamming. So, the routing algorithms need to be adaptive in order to reflect the changes in link connectivity.

In networks with centralised control, all routes are determined by the control station, which acts as a routing server. To this end, all nodes transmit connectivity information on a regular basis to the routing server which then calculates the optimal routes for every source-destination pair. The criterion for optimality is not always the shortest path. It could, for example, be the path which has the least traffic on it. In distributed routing, each node is responsible for maintaining and updating its routing table. This is done with the aid of connectivity information gathered from its neighbours.

A particular routing technique which requires no network control is flooding. In flooding, each node transmits every packet it receives on every outgoing link. The main problem with this technique is the duplication of packets and the consequent waste of bandwidth. This duplication may be reduced by having a sequence number in every packet, so that if a node receives a packet that it has already transmitted, it is discarded. The advantage of employing flooding is twofold. Firstly, it is immune to topological changes and link breakages. This is because every existing route between a source destination pair is tried, and this guarantees delivery of the packet as long as a single route exists. Secondly, since every route is tried, there will always be a packet which has traversed the optimal route. In networks where the connectivity changes too rapidly for dissemination of routing updates, flooding may be the only viable routing technique.

4. ATM performance measures for radio networks

4.1 End-to-end delay

The design of a packet radio network using ATM involves the consideration of many choices that interact in a complex fashion. Consequently, there are many performance measures of interest in the operation of such networks. However, an important issue here is the end-to-end delay that packets experience. This is because real time services such as speech are not very tolerant of excessive delay, and the very feasibility of using the network to provide these services is dependent on this parameter. Since speech is an important service that should be provided by the network, the rest of the discussion on performance measures concentrates on speech transmission. However, much of what is said is applicable to the provision of other real time services as well.

In networks using ATM the end-to-end delay is composed of various components that introduce both fixed and variable delays. The resultant delay is thus a variable quantity, whereby different packets may undergo different delays. This poses a problem for the transmission of speech, since accurate replaying of the speech signal cannot be carried out if the total delay is a variable. This is because the packets now need to be buffered at the destination in order to ensure that all the necessary packets are available for replay at the correct time instants. The buffering should be carried out such that each packet is held for the duration of the maximum variable delay. However, since this maximum variable delay is unknown, an estimate of it is used such that any packets that arrive with a delay greater than this estimate are automatically discarded. So, the setting of the maximum delay is a tradeoff between the desire to minimise packet loss and the desire to have as low an end-to-end delay as possible.

Under normal operating conditions, the end-to-end delay is composed of the following constituent delays :

1. Packetisation delay - fixed
2. Propagation delay - fixed
3. Switching delay - fixed

4. Queueing delay - variable

In addition to this, there are other delays that could occur occasionally and thereby contribute towards the end-to-end delay. These are delays due to collisions and delays due to link breakages. Collisions occur when two nodes, which are not in radio range, transmit simultaneously to another common node. In this event, the packets are lost and have to be retransmitted, thereby causing extra delays. The scheduling of the retransmissions depends on the access scheme that is being used. The other contributory factor towards occasional extra delays is link breakages that occur due to the topology changes that are generated by nodal mobility. In the event of link breakages, the packets have to be re-routed and this requires the generation of new connection identifiers in the packet header. In ATM cells, these connection identifiers are given as the Virtual Path Identifier (VPI) and Virtual Channel Identifier (VCI), a two level identification. In order to do this, every node needs to have a list of links that are operational, and corresponding VCI/VPI pairs that map onto these links.

In terms of normally occurring fixed delays, the packetisation delay, t_p, is the worst. This is the delay that occurs at the transmitter when waiting for each cell to be filled. This is a function of the voice encoder rate and packet size and is given by

$$t_p = I/R$$

where I is the number of information bits in an ATM cell and R is the voice encoder rate. Given the narrowband HF radio channels that are being considered here, the channel transmission rates are limited and this limits the range of vocoders that can be used over such channels. The current state-of-the-art is 4.8 kbit/s with 9.6 kbit/s a future possibility. The Table below shows the packetisation delays that would occur if this range of vocoders were used to transmit speech. These delays make speech transmission difficult over narrowband HF radio networks, especially since there are further delays that cells will encounter in the network. So, in order to transmit speech using ATM over narrowband HF radio networks, the packetisation delay must somehow be reduced. Given that ATM is used, it is not possible to reduce the packetisation delay by changing the cell size. However, a possible option is to transmit cells that are only partially filled with voice information. This will be at the expense of using bandwidth inefficiently - something that ATM systems claim to avoid!

Table 1 Packetisation delays on HF link

Speech encoder rate (kbit/s)	Packetisation delay (ms)
2.4	156
4.8	78
9.6	39

The propagation delay is the cumulative time taken by the signal to travel between every pair of nodes on the chosen route from source to destination. In the context of an HF network this delay is negligible and can be ignored in the analysis. The switching delay is the time taken for a cell to be switched from an input port to an output port. This is dependant on the switching architecture and hardware used in the switch. It is generally negligible and can be ignored.

The final component in the normal end-to-end delay is the queueing delay. This delay occurs at every switching node and is the time period between the placing of a cell in an outgoing queue, and the transmission of that cell. In some cases there would be no delay, whilst in other cases the cell would have to be queued until all the cells preceding it have been transmitted (unless the cell is subject to priority). This is, therefore, a variable delay and is dependant on the arrival rate of cells at the switching node. It is difficult to quantify and is characterised by a probability density function (pdf). The total queueing delay may be obtained by the convolution of the individual pdf's at each node. A maximum value for the queueing delay may then be estimated by selecting a percentile (say 95th) from the resulting distribution. This maximum value for the queueing delay is used at the destination when playing out the speech packets.

4.2 Cell loss

The above discussion has concentrated on how the feasibility of speech transmission over narrowband HF radio networks using ATM, is affected by the end-to-end delay. Another factor which affects the performance of these networks is cell loss. Cell loss occurs due to buffer overflow or errors in the header. If the network is congested, this could result in buffer overflow, with consequent discarding of cells. To alleviate the effect of cell loss due to buffer overflow, the CLP (cell loss priority) bit in the cell header is used to indicate cells of low priority. The scheme operates by comparing the buffer queue length with a predetermined threshold. If the queue length exceeds this threshold, all low priority cells that arrive at the node are discarded. Thus, the buffer consists of all cells up to the threshold queue length and only high priority cells beyond this threshold. Errors in the VPI/VCI field in the header also cause cell loss. If the errors transform the VPI/VCI field into another valid number, the cells are misrouted and arrive at the wrong destination; otherwise they are simply lost. In radio networks, however, the probability of cell misrouting is minimal since there would only be a limited number of valid VCI/VPI pairs.

The effect of lost cells on the output speech depends on the amount of speech information that is lost. This, in turn, depends on the amount of speech information contained in each cell and the number of consecutive cells that are lost. For example, at a transmission rate of 2.4 kbit/s, each cell contains approximately 150 ms of speech information, so the loss of more than three consecutive cells would be significant since this represents about (or more than) half a second of speech. Furthermore, consecutive cell loss is a distinct possibility due to the burst errors that are caused by signal fading. Automatic Repeat reQuest (ARQ) as a means of error control is not really a valid option since this would introduce further delays. A possible solution may be to have tighter error correction coding on the header by using some of the bits of the VPI/VCI field. Another option is to increase the possible transmission rate so that each cell would contain less speech information, thereby making the loss of cells less critical.

5. Gateways

5.1 Introduction

The desirable attributes of TPRNs include, among others, the ability to inter-work with commercial public telecommunications networks. This involves interfacing between radio networks and broadband networks. The radio network is not just a radio access mechanism to the broadband network, but a fully self-supporting network based on different protocols and media than the broadband equivalents. It is because of this that interworking between the two dissimilar networks is required. The goal of interworking would be accomplished through the use of gateways.

Each gateway would be a fully functioning mobile node within the TPRN. A gateway that is not connected to any broadband media would act as a normal TPRN node, receiving and relaying TPRN calls and messages. There may be more than one gateway within each network or one gateway between two or more networks.

The gateway would utilise a broad range of transmission media to connect to the public telecommunication networks, such as fibre, satellite, microwave, or UHF links. It is because of this that a media independent approach to the design of the gateway is required, allowing multiple mixed media to be used at one time.

The gateway should be designed to be flexible in respect to its protocol architecture, service provisioning, hardware, and deployment strategies, to allow for the evolution of both the military and commercial communications standards and operation procedures Because of the media independent approach, and the desire to use commercial equipment where possible, the broadband side logic is left to the standards developers and hardware providers.

5.2 Gateway deployment

A Tactical Packet Radio Network would provide a means of conveying information to and from the soldier in the field. A vast range of deployment strategies apply to tactical units, depending on the terrain and opposition, and it is because of this that the accompanying communications networks must be equally versatile. The versatility required in the gateway design can be seen in selected examples of deployment strategies shown in Figure 5.1.

In case A, the gateway is not connected to the broadband infrastructure, and hence is only acting as a normal node within a stand-alone radio network. It may, however collect the information needed for operation as a gateway node which would be utilised as soon as a connection to the broadband infrastructure could be effected. When a gateway is connected to the broadband infrastructure (case B) it may now handle inter-network calls as well as gather and distribute information to and from other TPRNs. The broadband infrastructure could take the form of military or commercial networks. In the event of a gateway failure, a TPRN could amalgamate with another TPRN, or just request gateway access from another TPRN. This second option would result in case C, where one gateway services two separate TPRNs. To

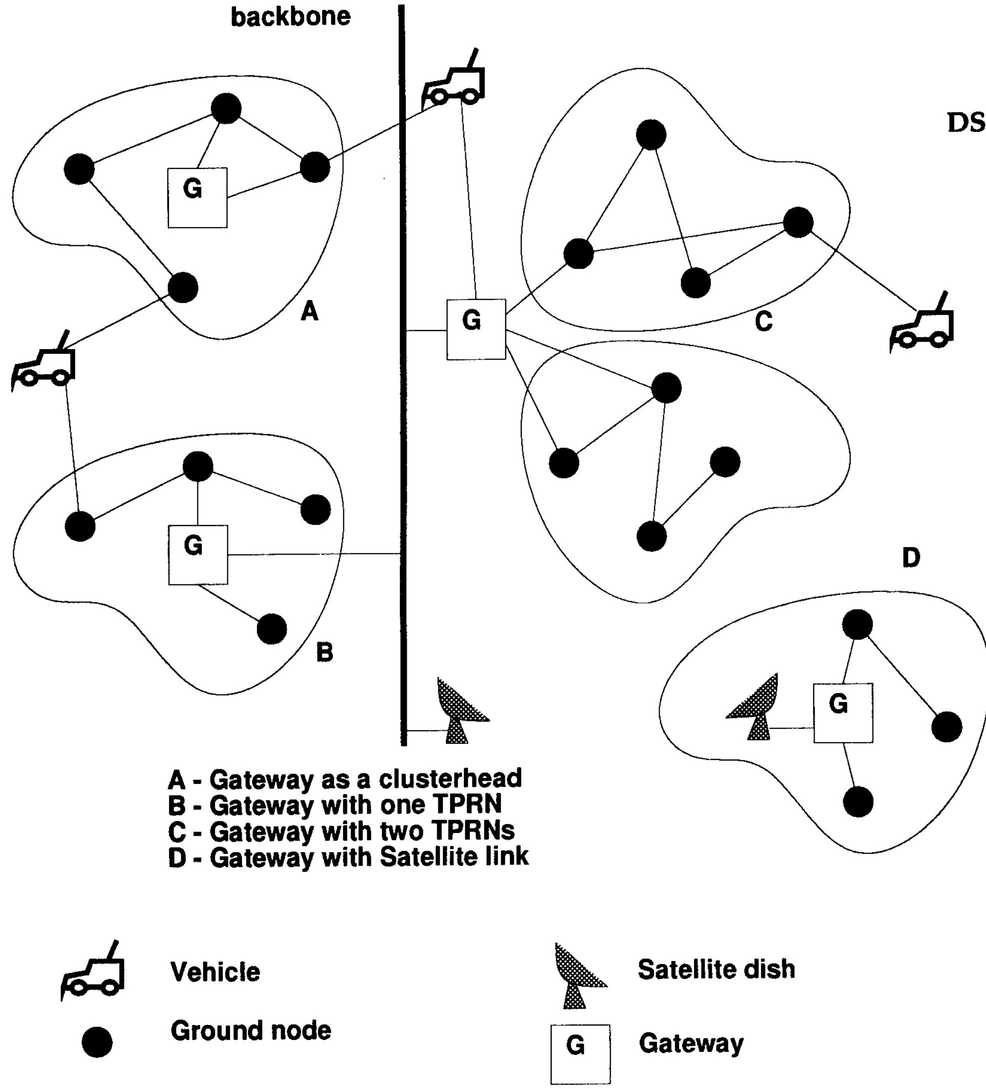

Fig. 5.1 - Gateway Deployment Strategies

avoid transferring this information across the network to the new gateway, the gateways should keep a distributed database of the current network status, so that the new replacement gateway can initialise itself more efficiently via the broadband backbone. The actual implementation of this feature should be located within network management routines [6].

The gateway must also be able to utilise the best, cheapest, or most available broadband media at any given time. The choice of media will depend on the degree of mobility required, jamming or damage done to media, or any other criteria applicable at the time. A satellite link (case D) could provide a gateway with more mobility than a fixed fibre, but may be vulnerable to jamming. The gateway must be able to switch between available media with the minimum of interruption to the service that it provides.

5.3 Functions of a Gateway

A gateway may have to handle many functions, depending on its configuration at a given time. A common set of services would be signalling, user service mapping, and routing between networks. If a more capable gateway is provided, then the provision of supplementary services and specialised management may be possible.

5.3.1 Handling user services

An important function of the gateway is to map user services required of the TPRN, onto equivalent services provided by BISDN. This is due to the large differences in throughputs of the two networks. Figure 5.2 shows the expected bit rate ranges of future BISDN services that might be mapped onto the TPRN equivalents.

The HF channel is, at present, capable of a throughput of 4.8 kbit/s [7]. The aim of future research is to be able to provide an average of 9.6 kbit/s. The cut off line within Fig. 5.2 reflects this capability. A limit of call duration will also be probably placed on the vertical axis, however this will depend on the call type.

Voice
BISDN provides a standard 64 kbit/s digital voice service. Because of the low bit rates available within the TPRN, voice calls will be mapped onto a low bit rate digital voice. A 100 bit/s canned voice service is also an option for delivering simple commands to a soldier in the field.

Data
The data transfer service used in a TPRN would most likely be a modified version of X.25, a current standard used by many public networks for data transfer. The data itself need not be mapped within the gateway, however, for message transfers it would act as a store and forward device between the BISDN and TPRN networks.

Image
High resolution image data (eg. satellite images) would require transfer times as low as possible. The data would be sent in the most acceptable compressed form available and would not be converted at the gateway. Facsimile quality documents could either be sent over an X.25 connection or, if delivery time is not crucial, by encapsulation into an X.400 message.

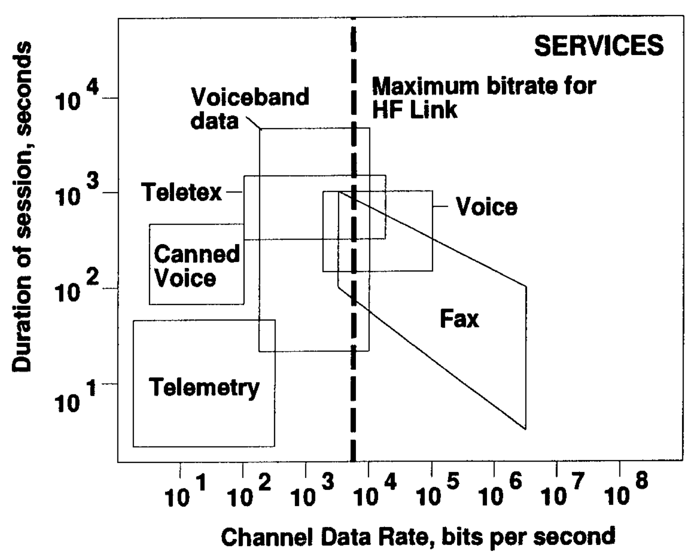

Fig. 5.2 - Service requirements

Messaging

X.400 messaging is seen as one of the most useful services within the TPRN. The connectionless nature of messaging suits the store and forward nature of the TPRN. An X.400 Message Transfer Agent (MTA) located within the gateway, would not only act as a store and forward device, but also as a converter between different document formats used within the TPRN. The benefits of using the connectionless approach to send messages, such as fax, voice or visual data, are many. Multiple links can be used to reach the user, also the overheads associated with call setup, teardown and QOS assurance can be avoided.

It appears that, while most services would require protocol information mapping of some form, the problem of converting actual service data may only need to occur with voice. The other services would need to be configured correctly so that end to end negotiation procedures occur seamlessly.

5.3.2 Mapping signalling protocols

The rather dissimilar signalling protocols at both the link and network layers point to a mapping at the level of Network Layer as the only possible interworking solution. There are two possible approaches to mapping the signalling Network Layer protocols between TPRN and BISDN: mapping the networking protocols used within the telecommunications infrastructure, or mapping the user access protocols to that network (User Approach) [8].

The User Approach is the preferred choice for the gateway for the reasons explained in reference 8. It implies that the gateway is a user to both networks, and can receive the incoming call, modify the control and user data if necessary, and pass the call to its destination. In this approach, there is great flexibility in the choice of structure of the TPRN protocols, as the gateway effectively isolates the protocols on each side. The gateway's hardware interface to BISDN would be a standard User Network Interface (UNI), thus offering cost and complexity benefits.

5.3.3 Call handling functions of a Gateway

The routing of all calls arriving or departing from the gateway must be handled by the gateway. To reduce message length, the full ISDN address would not be used within the TPRN. Only a limited number (eg. 50) of nodes is expected within each distributed network and a 4 character address would suffice for intra-net calls. All inter-net calls would need to carry the full ISDN address, which would be constructed at the gateway by combining the gateway's address with the TPRN node's address.

On receipt of an incoming call to the TPRN, a check is made if the destination node is within the subnet attached to the gateway, and if not (eg. due to the mobile destination node changing its location), the call is redirected using the BISDN call control procedures. The redirection address is determined by the routing (location) tables maintained within the gateway which are updated regularly via the broadband network infrastructure.

There is a possibility that a mobile user may call another mobile user in a remote TPRN. Such a call would be routed to the local gateway, and a call would then be established between the local and the remote gateways. This should be transparent to the users. The local gateway would be responsible for looking up its location database, reconstruction of the full destination ISDN address, and for setting up the call.

It is possible that a node moves from one TPRN subnet to another while a call, or message forwarding, is in progress. In effect, an action equivalent to a call handover must occur. It must be handled by both the node's local and destination gateways and involves location update, putting the call in progress on hold, and re-routing of packets. The amount of information transferred between gateways due to the call handover does not pose a problem because they are connected by a broadband network.

5.3.4 Provision of supplementary services

One of the issues for the design of a TPRN architecture is that it should, ideally, be capable of handling or emulating ISDN-like supplementary services. Provision of services such as call forwarding, closed user group, and conference calls, should be addressed in the design of the network architecture.

6. Gateway architecture

6.1 Gateway protocol architecture

The design of the gateway is complicated by the fact that it may also be a fully functioning TPRN radio node. This results in a complex architecture of protocols within the gateway and requires special techniques to describe accurately the functions of these protocols. A simplified representation of this protocol stack is shown in Fig. 6.1. In this diagram the gateway can be seen to connect to other TPRN nodes via its radio protocols. These protocols organise the radio access, frequency management, and some network organisation functions. Above these protocols sit the networking protocols that organise call setup and clearing, and higher level networking issues.

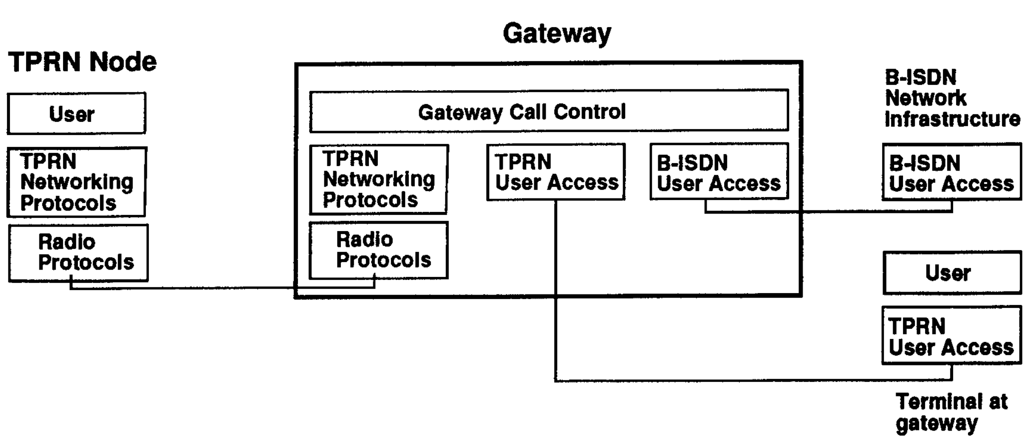

Fig. 6.1 - Access protocols within the Gateway

On the other side, access to the Broadband BISDN network is achieved with a version of the standard BISDN User Access protocol (Q.2931 [9]. This protocol allows access to the full set of services provided by the emerging BISDN communications infrastructure. Services such as multiparty and multiconnection calls, as well as a large variety of call redirection and priority facilities.

In the centre is the TPRN access protocol that allows users of the TPRN to send messages or create calls between users. This protocol is present within the gateway to allow a user located at the gateway to access the narrowband network. The functionality of the access protocol is identical to the access protocols located at every TPRN node.

The Gateway Call Control sits above the three protocols (TPRN Network Protocol, TPRN access protocol, and BISDN access protocol) shown in figure 6.1. This application receives primitives from the protocols associated with an incoming call, makes decisions and issues primitives to outgoing protocol entities. It is here that the mapping of signalling information occurs. The Gateway Call Control also controls the service mapping and supplementary services. A more in depth discussion of the protocol architecture can be found in the following references [6,8,10]

6.2 Media Independence

The gateway would have to handle many different types of interconnection media to the broadband infrastructure, such as fibre, satellite, and UHF radio. The list of media can also include the HF or other radio media used within the TPRN. Thus a media independent way of describing services and call parameters is required to request a call when the destination medium is unknown. A symmetry may also be achieved between each side of the gateway, because users on each side need not know what media they will be using on the other side of the gateway. The Gateway Call Control makes the `choice of media' decision and routes the messages accordingly. This approach allows flexibility in the hardware configuration of a gateway, because transmission media can be seen to be `card modules' that fit into `slots' (Fig. 6.2). The broadband `cards' could be standard commercial hardware, with standard Call Control software.

In a similar way, the TPRN `cards' would represent a standard TPRN node, which would be inserted into the gateway to allow access to TPRN users. In the case of two

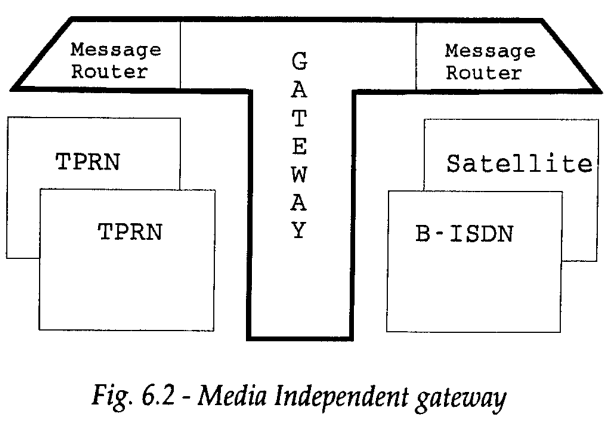

Fig. 6.2 - Media Independent gateway

TPRNs accessing the same gateway, either one or two TPRN cards could be used to access the networks.

7. Conclusion

The design of TPRNs involves many issues that are highly interdependent. Careful consideration needs to be given to these issues in order to ensure that the correct choices are made. There are performance limits that need to be considered if ATM were to be used in a TPRN. In particular, the transmission of real time services such as speech, is affected by the end-to-end delays that are observed over radio networks with low throughputs.

The interfacing between BISDN and a TPRN is done via a gateway. The gateway could be a normal TPRN node with added functionality, or a specialised module. It must utilise the cheapest and most available media to access the broadband infrastructure. As such, the design of the gateway, in terms of its protocol architecture, should reflect media independence.

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Appendix A - Abbreviations

ARQ	Automatic Repeat reQuest
ATM	Asynchronous Transfer Mode
BISDN	Broadband Integrated Services Digital Network
CLP	Cell Loss Priority
CSMA	Carrier Sense Multiple Access
DORIC	Defence ORganisation Integrated Communications
HF	High Frequency
ISO	International Standards Organisation
MTA	Message Transfer Agent
OSI	Open Systems Interconnection
QOS	Quality Of Service
TPRN	Tactical Packet Radio Network
UHF	Ultra High Frequency
UNI	User Network Interface
VCI	Virtual Channel Identifier
VPI	Virtual Path Identifier

The DORIC Program: Integrated Tactical Radio Network Design Issues

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19. Abstract

The report describes some of the issues involved in the design of integrated radio networks. The performance limits that arise when ATM is used are examined. Gateway design is discussed in terms of their functionality and protocol architectures.