

MOBILE NETWORKING TECHNOLOGY WITHIN INSC

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ABSTRACT

We provide an overview of the INSC Mobility Task area efforts including: a brief overview of technology areas investigated, a discussion of research developments, and example results from experimentation and demonstration. The main areas investigated were Mobile Ad hoc Network (MANET) routing and mobile IP version 6 (MIPv6) protocols. Early simulation efforts were performed along with more recent network emulation and live experimentation. Network mobility experimentation and demonstration has taken place in both localized, controlled coalition environments and between participating coalition laboratory sites across the INSC WAN. The localized testing environments enabled more meaningful performance analysis while the WAN tests have demonstrated architectural and interoperable functionality. Example results are presented describing example MANET routing and MIPv6 performance analysis. Finally, some early lessons learned are discussed along with recommended areas of further work.

INTRODUCTION

Enabling improved network effectiveness during mobile, wireless operations is a critical network centric warfighting enhancement. Within the Integrated Networks for Secure Communications (INSC) project the Mobility Taskgroup, Task 6 (T6), is concentrating on investigating and demonstrating emerging mobile networking technology areas. The T6 focus is targeting emerging open standard technology areas and exploring how such components may play a role within coalition network architectures.

Figure 1 demonstrates some of the potential architectural variability involved in solving broad network mobility problems [MPC01]. Under this effort, we are considering the mobility of both end users and of portions of the networking infrastructure itself. In military applications, wireless network infrastructure nodes (e.g., routers) are often on the move in addition to or in conjunction with end users. Thus, infrastructure and local router nodes require adaptability in addition to the end users. From an INSC architectural standpoint, we envision different protocol enhancements (e.g., end user and mobile infrastructure) both being deployed at a broader internetworking level to solve various types of scenario-dependent and operational requirements [INSC1].

The T6 team has split task investigations into infrastructure and edge system mobility problem areas. First, the present INSC mobility effort is investigating and addressing mobile ad hoc network (MANET) routing technology alternatives [MC99]. The demonstration focuses on the use of evolving IP-based MANET solutions to support mobile wireless nodes forming a dynamic localized infrastructure. This technology supports both IPv4 and IPv6 operations.

Second, the edge system mobility problem is being examined through demonstration of evolving Mobile IPv6 (MIPv6) technology and potential hybrid variants [MIP03]. This edge system mobility demonstration supports coalition network nodes roaming among multiple network access facilities, while retaining their home-based IP addressability. Consideration is also given to dynamic edge user nodes without requirements for global IP address identification and active session retention that may be more directly supported by dynamic configuration and routing support at the edges of the INSC infrastructure (e.g., DHCPv6 or IPv6 stateless autoconfiguration).

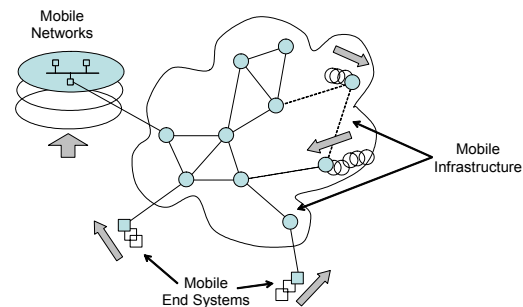
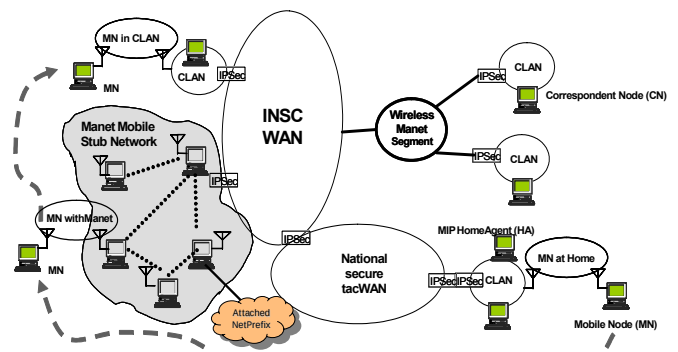


Figure 0: Architectural Variations of Mobility

Figure 2 provides a high level INSC architectural view of example mobility demonstrations planned for the INSC architecture. The MANET segments depict wireless, mobile routing capabilities in localized parts of the architecture. In most testbeds, this has been instrumented within national network segment areas and emulates localized adaptive routing support for highly dynamic, wireless network users and platforms. Figure 2 also illustrates mobile edge system demonstrations involving MIPv6 technology. As shown, a mobile node (MN) associated with a home network migrates throughout the INSC architecture maintaining network communications with a correspondent node (CN) throughout the course of the demonstration.



Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE 2007		2. REPORT TYPE		3. DATES COVERED 00-00-2007 to 00-00-2007	
4. TITLE AND SUBTITLE Mobile Networking Technology Within INSC				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Research Laboratory, Information Technology Division, 4555 Overlook Avenue, SW, Washington, DC, 20375				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES The original document contains color images.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES 7	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

TECHNICAL SCOPE

As mentioned, T6 roughly split INSC investigations into edge system and infrastructure mobility problem areas. As one of the two primary areas of scoped work, we are examining and applying MANET routing technology alternatives. The dynamic routing protocols being considered play a primary role in supporting multi-hop routing within highly mobile, localized segments of the INSC architecture. For the purpose of test and demonstration execution, we established wireless routing gateway points within National testbeds that support MANET stub network operations and provide routing connectivity to the larger fixed INSC routing infrastructure. Figure 3 illustrates how this works within the testbed and depicts a mobile router gateway supporting a mobile routing area consisting of prototype computers/routers (these nodes can support additional attached fixed networks that are also dynamically advertised prefixes). These mobile segments presently operate as stub networks in relationship to the WAN transit networks, although with attached prefix advertisement some transit functionality is supportable if carefully managed. Again, these network areas represent operational requirements where a set of dynamic users or nodes needs highly adaptable infrastructure support.

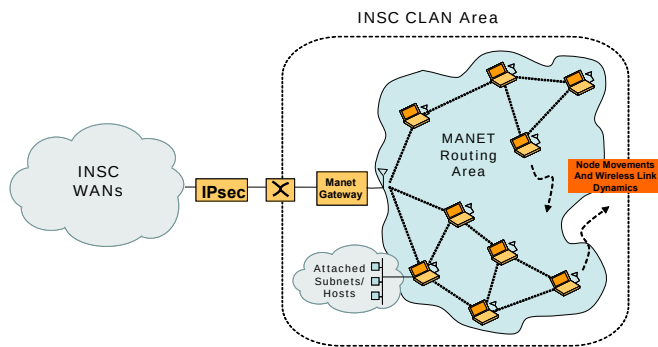


Figure 0 : Mobile Routing Area and Gateway

Within INSC, the joint desire was to focus on open specification work ongoing within the IETF. For Phase 1, the Optimized Link State Routing (OLSR) [CJ03] protocol was the focus of most MANET routing investigations although some Ad hoc On-demand Distance Vector (AODV) [PBD03] investigations also took place. A typical local testbed configuration for the OLSR routing area(s) is shown in Figure 3. The stub gateway router pictured in Figure 3, at a minimum, has one wireless interface for MANET routing support and one fixed interface (e.g., Ethernet) for external INSC connections. In most National testbeds, participants are using various 802.11b wireless local area network (WLAN) technologies to support MANET and Mobile IPv6 operations. These interfaces are operated in ad hoc mode allowing the MANET routing protocol to control the forwarding of packets. This demonstration targets a “proof-of-concept” capability to test and demonstrate IPv6 and IPv4 MANET mobile routing and

user roaming capabilities but does not closely examine numerous possible tactical wireless technologies. It is envisioned that the networking solutions investigated are flexible networking technologies and can be adapted to multiple application areas.

As the second primary investigative area, T6 is examining MIPv6 technology and potential hybrids. Related experiments involve examining MIPv6 operation as a node roams within and among various network areas demonstrating the establishment, handoff, and maintenance of appropriate MIPv6 associations and connections. T6 team members have done significant background investigations of MIPv6-oriented solutions for edge mobility and are tracking ongoing progress with related standardization issues within the IETF. To support collaborative coalition testing, T6 established operating Home Agent (HA) nodes in particular participating national testbeds (i.e., Italy and Germany) and developed a strategy for other participating nations to perform surrogate host roaming demonstrations and tests at distributed locations across the INSC WAN architecture. A range of surrogate addresses spaces for roaming node tests was issued to each participating nation to support these experiments. This allows distributed testing throughout the architecture with minimal testing coordination and planning. The general WAN-based MIPv6 testing approach is depicted in Figure 4.

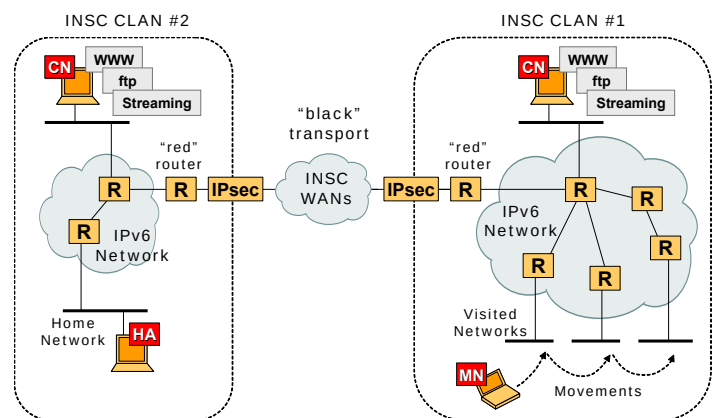


Figure 1: Mobile IPv6 supporting INSC end system mobility

EXPERIMENTAL METHODOLOGY

INSC T6 participants have agreed that a proper examination of network mobility technology requires specialized investigative work to produce meaningful performance assessments and recommendations to the operational and research sponsorship community. In the early stages of this project there existed limited software tools and methodologies addressing mobile network analysis and assessment. One of the significant outcomes of the INSC T6 work is the establishment of some testing methods and tools to improve analysis of protocol performance and behavior. Here we quickly review

relevant methods and tools that were adapted and applied in T6 work.

First, to examine performance a method was needed to produce dynamics or mobility within a network topology. Initially, T6 performed some examination of mobility and dynamics in a networking simulation environment [NS2]. Moderate size network simulations (~50 node networks) were used to perform initial analysis studies and T6 began targeting smaller mobile network segments (~10-20 nodes) for actual mobile routing node experiments. Because of the difficulty of controlling and repeating actual field tests, mobile emulation methods were adopted within testbeds. Various participants' approaches here have varied and approaches used for MIP testing are different than those used in MANET testing. The usefulness of such dynamic network emulation DOES NOT replace the value of actual field test experiments, but the capability provided repeatable and controlled testing required for more thorough investigation needed in the early stages of technology evaluation. An example of how the Mobile Network Emulator (MNE) has been adapted to support controlled, repeatable INSC MANET experimentation is shown in Figure 5 [CMW03].

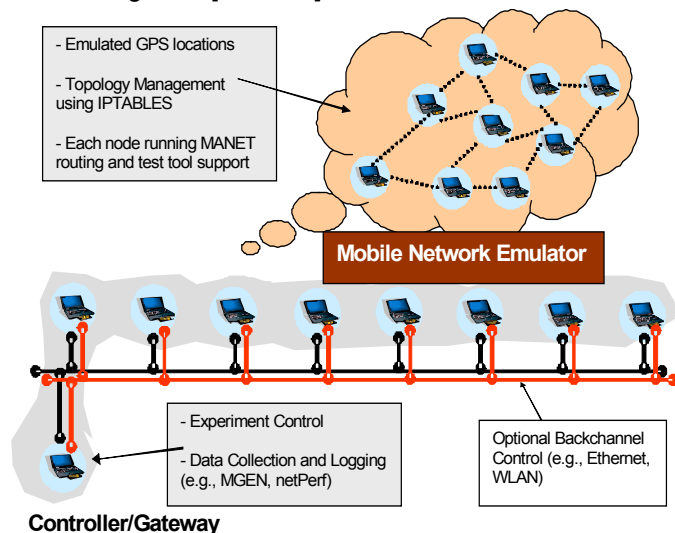


Figure 2: Emulation of Mobile Topology Dynamics

The bubble diagram shows an emulated network topology involving multiple hop routes controlled from model generation or actual recorded mobility scenarios. MANET routing or mobility protocols under examination operate within this environment while nodes undergo active topological change. The types of technical observations collected in such experiments include; mobile routing convergence, supportable network data throughput, packet loss and delay statistics, and other detailed protocol behavior. Task 6 also developed and applied specialized test procedures, data collection, post analysis, and visualization tools to support unique requirements of mobile network testing and analysis. In the case of the MNE, represented in Figure 5, the same set of traffic tools, visualization, and post analysis methods are applied in field

testing. As an example, early OLSR-based field trials were executed within INSC and in some cases mobility traces were recorded and used later to drive the mobility patterns within emulation tests with the same traffic patterns.

T6 also developed functional extensions to existing MANET routing source code to enhance existing prototype capability. These functional extensions included: attached network prefix advertisement, mobile routing gateway discovery and advertisement, improved debugging and dynamic routing analysis tools, and IPv6 porting of IPv4 routing implementations.

The breadth of possible combinations of protocol layer interactions, traffic models, and mobile network scenarios made T6 experimental formulation technically challenging. Team members agreed to limit the test scenarios to a reasonable number achievable under the tasking and covering a reasonable cross section of analytical interest [T603]. To improve the ability to analyze and understand mobile networking routing performance we enhanced related debugging and logging facilities to track and capture MANET routing performance. In the case of OLSR routing, we can trace local neighbor and topology table information throughout the course of a demonstration experiment and we are able to visualize the routing protocols view of the dynamic topology as it changes during an experiment.

EXAMPLE EXPERIMENTAL RESULTS

While participant organizations (POs) conducted live experiments between mobile nodes and MANET routing areas across the INSC WAN, detailed performance tests were carried out under more localized controlled environments. This allowed for better scientific assessment of detailed areas of protocol performance and behavior. These findings are critically important to the overall T6 output of assessing the related technology maturity and in collecting detailed performance measures. A more thorough coverage of these results is planned to be presented in the upcoming INSC T6 Final Report.

Here we present a few samples of experimental results collected to date within T6 using various mobility test scenarios and related tools.

OLSRv6 MANET Routing Experiment Examples

INSC T6 has executed numerous mobile routing experiments under controlled conditions to examine various aspects of mobile routing protocol performance. The following example experiments were performed using a particular IPv6 port of OLSR routing code, based upon an early version 3 of the IETF OLSR draft specification. The code was ported to IPv6 by CRC and this code also contains a number of other NRL and CRC modifications to enhance the protocol behavior and functionality. A more recent implementation of the OLSR specification (both IPv4 and IPv6 capable) has also been developed by NRL and additionally released to INSC participants for optional experimentation.

The emulation scenario for the set of example experiments to be presented was as follows:

- 10 total operating MANET routing nodes (laptops)
- 802.11b operating at raw link rate of 2 Mbps
- 1 node acting as the INSC gateway
- Traffic scenario: All mobile nodes source traffic towards the gateway
- Mobility scenario: random waypoint motion model
- Traffic generator: MGEN (TCP traffic generation was a streamed secure shell (ssh) connection)
- DiffServ QoS Filtering/Forwarding Enabled on MANET Router System (Routing Control Marked)
- Traffic scenarios:
 - o UDPv6 (3 phase increased loading, all 10 nodes sourcing traffic), 256 byte packets in this example.
 - o TCPv6 (all nodes but gateway (9 nodes) source stream traffic to the gateway), interface MTU is 1280 bytes per INSC direction.
- Routing Protocol Parameters:
 - o 0.25 sec hellos, 2 sec TC, neighbor link hysteresis function ON

The first example experimental result in Figure 6 shows the total IPv6 UDP traffic goodput¹ realized at the MANET gateway from all mobile nodes during a three phase traffic loading test. The three phases of the test are designed to achieve low, moderate, and heavy congestion conditions using 802.11b, 2 Mbps raw link rates. Each loading phase is 10 minutes long and provides enough time for significant routing changes to occur within the topology. The maximum hop count to reach the gateway in this example scenario was observed to be 4 hops. We were able to visualize and record routing information in both partial and full link state modes of OLSRv6. Idealized goodput (no loss, no mobility effects, and no multi-hop or contention-based wireless MAC limitations) would result in 100, 500, and 1000 kbps. The 1000 kbps represents an operating region that due to MAC contention and multi-hop relaying the MANET network is experiencing significant traffic loading. Figure 6 demonstrates that under light and moderate loading excellent UDP goodput is achievable under multi-hop and dynamic topology conditions. Some slight drops in goodput noted at the 800 sec mark are due to repeatable mobility scenario conditions where a node becomes physically disconnected from all network neighbors for a period of time and then reenters the network area.

Under heavier congestion conditions additional loss and delay occurs but the routing protocol still demonstrated

effectiveness in delivering a significant amount of multi-hop user data under dynamic conditions. In other experiments executed, the protocol parameters (e.g., HELLO intervals) were adjusted to examine related effects and in most scenarios examined only minor differences were noted.

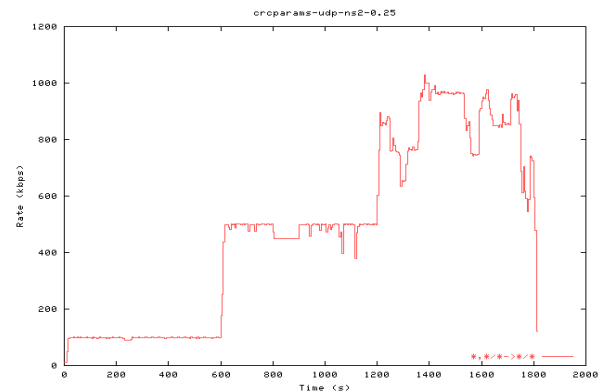


Figure 2: OLSRv6 Aggregate UDP Throughput

The next example test result presented was from an examination of the TCP transport effects under a set of scenarios. The experimental result in Figure 7 represents the total IPv6 TCP traffic goodput achieved to the gateway from all mobile nodes during a 15 minute test. Figure 7 further demonstrates the ability for OLSRv6 to support multiple simultaneous TCP streams under multi-hop and dynamic topology conditions. It should be pointed out that detailed TCP analysis can be quite complex and only a limited set of such tests were done under the present effort. Additional future mobile transport investigations are needed, but this does functionally demonstrate a basic capability to support multiple TCP streams and achieve reasonable aggregate goodput under dynamic MANET routing conditions.

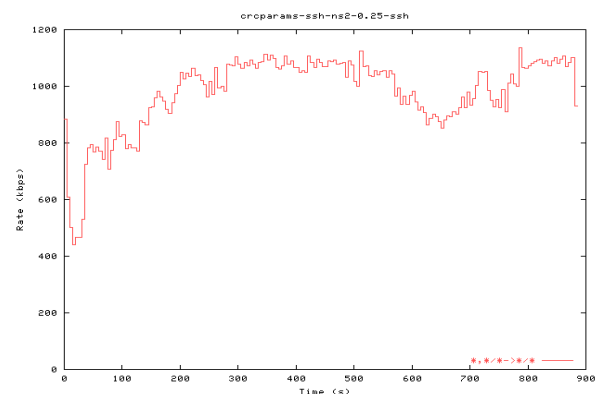


Figure 2: OLSRv6 Aggregate TCP Throughput

MIPv6 Mobile Node Experiment Examples

In addition to MANET performance evaluation, T6 efforts were dedicated to evaluate the ability of Mobile IPv6 to keep connections active while a mobile node changes its point of attachment to the network.

¹ Goodput: Usable end-to-end traffic throughput at the application layer.

The following example experiments were carried out to measure the performance of MIPL 0.9.5.1 for Linux, which is the reference Mobile IPv6 implementation chosen for the INSC demonstration phase. Detailed performance tests have been done localized, to exclude the non-related performance degradation caused by the INSC WAN from the analysis. The mobility of the Mobile Node (MN) was emulated using a Layer 2 switch with programmable VLAN configuration. With the emulator it was possible to control MN movements following pre-defined and repeatable mobility patterns.

All the example experiments presented here have been performed by cyclically moving the MN between two foreign networks (i.e. MN always away from home). Several testing sessions have been run changing the configuration of the main parameters affecting MIPv6 performance, that are the communication mode (i.e. bi-directional tunneling or route optimization) and the interarrival time between unsolicited Router Advertisements (RAs).

The first experimental result shows the *average handoff latency* experienced by the MN. It represents the delay occurring immediately after movement, during which it is not possible to send or receive packets, due to the delay involved in MIPv6 mobility management procedures. Figure 8 shows MIPv6 handoff latency for communications taking place in bi-directional tunneling (BT) and route optimization (RO). The measures demonstrate that the overall handoff latency generated by MIPv6 is higher when operating in route optimization, due to the extra signaling (i.e., Return Routability function) that must be exchanged between the MN and the communicating party to secure end-to-end location updates. The graph also shows that an effective way to reduce handoff latency is to decrease the movement detection delay by increasing the frequency of unsolicited RAs, and therefore accepting a higher signaling overhead on the localized access networks. Nevertheless, even when the movement detection delay approaches zero (with RA interval between 30 and 70 ms), the overall handoff latency remains higher than 2 seconds. This time value is not enough to enable uninterrupted real-time communications in mobility scenarios. This is mainly due to the high delay caused by Duplicate Address Detection (DAD) that must be undertaken by the MN after any movement. This is used to ensure the IPv6 address obtained on the new link is really unique.

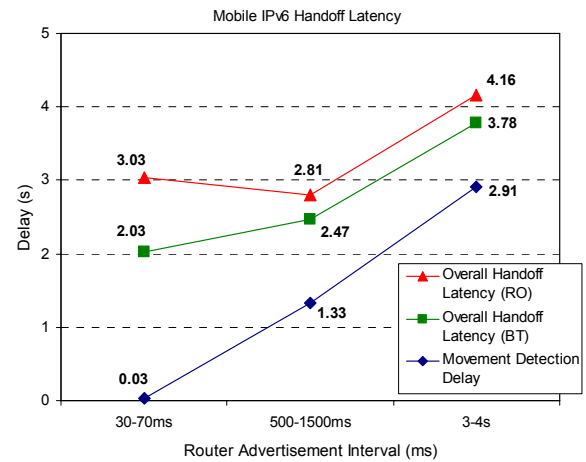


Figure 3: Mobile IPv6 Handoff Latency

The second experimental result shows the TCP throughput achieved by a correspondent node communicating with the MN in route optimization mode. Figure 9 demonstrates that in any network condition the TCP throughput decreases as the MN handoff frequency increases. However, even when the MN moves at the speed of six handoffs per minute, a reasonable upper bound in many operational scenarios, the measured TCP throughput is in the range 2.79-3.93 Mbps. This is quite high compared to the maximum of 5.99 Mbps, achieved when the MN does not move. This confirms the suitability of MIPv6 for best-effort applications like ftp and web browsing. It is also interesting to note that even if the MN remains still within the same visited network (i.e. handoff frequency equal to zero); the resulting TCP throughput is lower than the maximum throughput permitted by the test environment, which was measured by switching off MIPv6. This slight performance degradation is due to the protocol overheads introduced by MIPv6 to perform transparent packet routing towards the MN (i.e., tunneling, mobility headers, etc.).

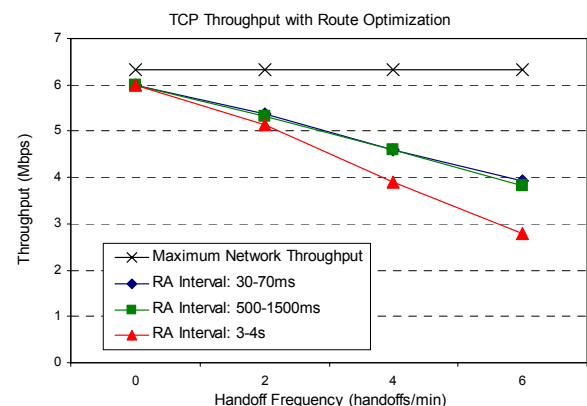


Figure 4: TCP Throughput in Route Optimization

Other Investigation Areas

T6 participants also performed optional investigations in combined MANET and MIPv6 functionality within the same network segment. In one example, CRC developed an experimental prototype that extended the functionality of OLSR MANET routing to support integrated MIPv6 signaling support. This functionality was of interest in a scenario where a routing node moves into an OLSR MANET and is also acting simultaneously as a MIPv6 node. In that case, the node needs to auto-configure its care-of-address and to propagate a Binding Update message containing its new care-of-address to its home agent and its correspondent node(s) located on the Internet. The functionality is complicated by the multi-hop nature of the MANET area and the desire to detect whether the node is entering a MANET area or simply a conventional single hop WLAN area. Automatic mode-detection and switching capability were introduced in each mobile node to facilitate handoffs between WLANs and MANETs. Mobility management across WLANs and MANETs was achieved and demonstrated through Mobile IPv6. In another case, where the MANET node is not a MIPv6 node but wishes to support roaming MIPv6 nodes on a second localized interface the conventional OLSR attached network advertisement process was used and demonstrated by the US and IT POs to support dynamic roaming MIPv6 support over a MANET routing area. This last scenario may be typical of vehicle scenarios in which the MANET router interface provides primary mobile routing infrastructure support and roaming MIPv6 users attach to localized fixed LANs within the vehicles or within a more localized region.

Other investigation areas included: an initial investigation into Hierarchical Mobile IP (HMIP), numerous MANET IPv4-based experiments, OLSR enhancement examinations to support attached network prefix advertisements, early MANET multicast examinations, and other mobile subnet technologies. Early results from these experiments will be discussed in more detail in the upcoming T6 Final Report.

FUTURE WORK AREAS

MANET routing is next generation IP technology that provides needed support for wireless areas of a network that contains dynamic links and potentially supports mobile routing nodes. As discussed in this paper, INSC Phase 1 participants began significant work in experimenting and evaluating with prototype MANET technology. Phase 1 has achieved significant progress in this area but T6 participants have reached consensus that there remain important evolving technical issues for exploration that will be ongoing beyond this initial effort. Early technology specifications are rapidly evolving and are expected to become significantly more stable over the next few years. To further explore this technology and better answer more detailed questions important to coalition interoperability and operational robustness follow-on focused work is recommended.

Mobile multicast technology investigations have been limited in INSC Phase 1 across the set of technologies being explored by T6. Nevertheless it has been a rich area of academic study for many years in the past and early potentially practical approaches are beginning to emerge from research, but these approaches require additional applied research to determine suitability and effectiveness for envisioned application scenarios.

Hierarchical Mobile for IP version 6 (HMIPv6) is an emerging technology area promising localized efficiency improvements and faster mobility support within localized regions of a network deploying significant numbers of MIPv6 type roaming nodes. This technology was not mature to significantly analyze during INSC Phase 1 but it has progressed significantly and future work is recommended by T6 participants to analyze and assess its military application and relevance.

Other areas of relevant future work related to mobile networking include: experimentation and analysis of protocol support for aggregate Networks in Motion (NEMO) (e.g., IETF work), enhanced MANET protocols supporting more heterogeneous networks (e.g., OSPF [M98] MANET enhancements [B03]), and improved anycast routing and distributed mobile network services.

Also, in Phase 1, INSC included no special tasking to analyze transport protocols in mobile, wireless environments, but this is an important future, complex study area. Due to the relevant dynamics in delay, loss, and throughput caused by wireless mobile environments transport protocols will face additional challenges over fixed networks in providing effective end-to-end service for multiple classes of user applications. It is anticipated that different MANET and mobile architecture solutions provide differing support behavior to IP transport and application layers and that this should be examined. Also, the type of topology, wireless environment, and mobility patterns tested may greatly influence the performance behavior.

In addition to the above, mobile networking technology recommendations must often balance often competing operational and design requirements for adaptiveness, security, and robustness. This is a significant challenge to be met in adapting future work to specific operational scenarios and needs. The adaptation of mobile networking to sensor systems is also an area for further detailed investigation and consideration.

CONCLUSION

INSC T6 is investigating, analyzing, and demonstrating numerous emerging mobile network technologies within a coalition networking environment. Working mobile network testbeds were constructed and integrated into the overall INSC network architecture. These mobile network test resources along with a set of novel test tools and methodologies were applied to support various experiments. Numerous localized performance studies and INSC WAN end-to-end interoperability experiments have been conducted for both MANET routing and MIPv6

technology areas by INSC POs. Several test examples and analysis discussions were provided in this paper.

Several basic lessons learned and general observations can be distilled from the present work done in T6. We summarize these as follows:

- Emerging MANET routing solutions for both IPv4 and IPv6 demonstrate improved network routing capabilities in dynamic, multi-hop wireless scenarios.
- Early simulation results demonstrate MANET-type routing approaches scaling reasonable well for supporting moderate sized network areas (e.g., 20-50 nodes)
- Early mobile network emulation and real world testing demonstrated reasonable effectiveness of OLSR MANET routing in small, dynamic areas (e.g., 10-20 nodes).
- MIPv6 technology demonstrated basic support for roaming nodes requiring IP address retention and identification within and across the broad INSC architecture.
- MIPv6 features demonstrated a number of performance enhancements over MIPv4. However, significant performance issues have been identified through testing regarding fast handoff, address configuration, and mobility detection methods.
- Network mobility assessment requires specialized testing tools and methodologies. T6 developed numerous such capabilities under this effort and demonstrated the utility in supportive analysis.
- Mobility support is still a rapidly evolving and challenging field of networking science and future R&D work should be planned for and supported. This is especially true in order to meet the more stringent demands of the dynamic warfighting environment.

The significant T6 accomplishments under the present effort were largely the result of significant technical ingenuity, dedication, and cooperation from each of the national participants. In conclusion, the Task Leader wishes to thank all those involved for their dedication and enthusiasm and for their contributions to the documentation and success of this ongoing effort.

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