Emerging Mobile Networking Architectures

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ABSTRACT

In this paper we discuss key issues and considerations relating to evolving mobile network architecture design and integration. We provide a quick view of the role of several mobile network technologies at an architectural level and then describe ongoing related work in mobile network evaluation and testing. Finally, some newer design work and initial evaluation being done on mobile ad hoc multicast forwarding is presented. In conclusion, we present our viewpoint on present and future work areas relating to cross layer protocol design for mobile wireless networks.

BACKGROUND

Enabling improved network effectiveness during mobile, wireless operations is a critical network centric warfighting enhancement. At the Naval Research Laboratory (NRL), we have been examining a number of emerging mobile networking technologies in simulation, emulation, and real world systems. This paper presents a number of mobile network architecture issues and then describes development and analysis efforts examining new concepts and protocols for adaptation to future military mobile network environments.

It is also important that future coalition network operations improve by supporting enhanced mobile and adaptive wireless networking capabilities. Under the ongoing Interoperable Networks for Secure Communications (INSC) project we have been applying some of the concepts and testing described here in the context of coalition networking research and development [3]. The solutions we address support both Internet Protocol version 4 (IPv4) and version 6 (IPv6) systems. IPv6 variants can offer some enhanced mobility mechanisms but in addition newer generation design frameworks raise additional design concerns that need addressing.

MOBILE NETWORKING ARCHITECTURAL OVERVIEW

Since there are many relevant mobile network scenarios and an additional number of relevant design approaches and concerns, it is important to present an architectural view of mobility design and some taxonomy definition before discussing protocol and testing details. Determining the suitability of various solutions to tactical environments is a multi-faceted problem area that is often scenario dependent. In military

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scenarios, wireless network infrastructure nodes (e.g., routers) are sometimes required to be on the move in addition to or in conjunction with end users. Thus, infrastructure and local router nodes require adaptability to expected dynamics in addition to the end users [6]. The unique behavior of wireless network interfaces also requires special consideration beyond typical wired Internet protocol design [5].

There are two fundamental mobile networking technology areas we cover in this paper: *dynamic wireless routing* technology, and *edge mobility* technology. Figure 2-a illustrates the architectural variability involved in broad networking mobility problems and demonstrates how we roughly split scenarios into edge mobility and dynamic wireless routing problem areas [2].

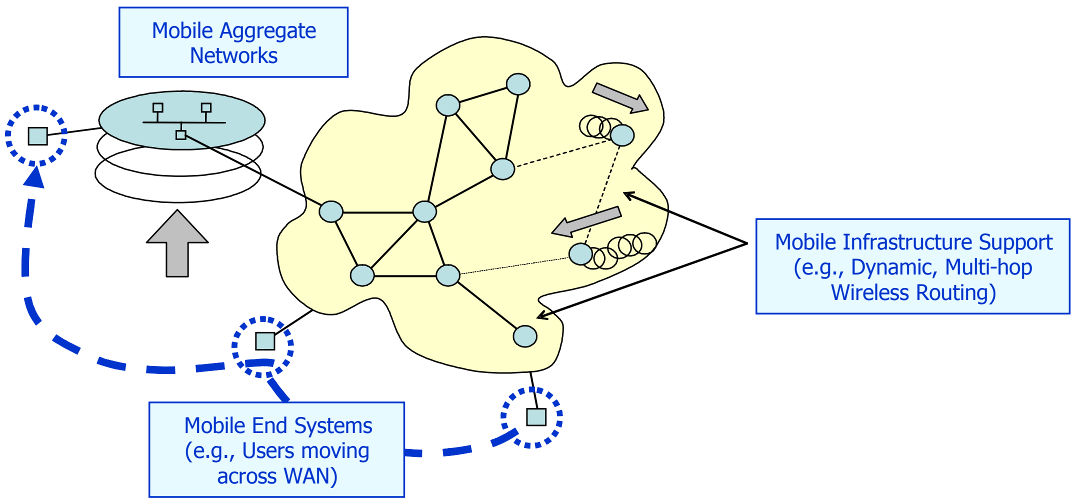

Figure 2-a: Architectural Variants of Network Mobility

IP-based Dynamic Wireless Routing Technology

We will first discuss dynamic wireless routing technology and how it can be used to help solve mobility problems. Figure 2-b, depicts an architectural example of mobile wireless routing using Mobile Ad hoc Network (MANET) technology to service a "last mile" tactical internetworking scenario. In addition to supporting mobile routing interfaces, the platforms shown in Figure 2-b may also have locally attached networks and MANET technology will support the dynamic advertisement of locally attached network prefixes.

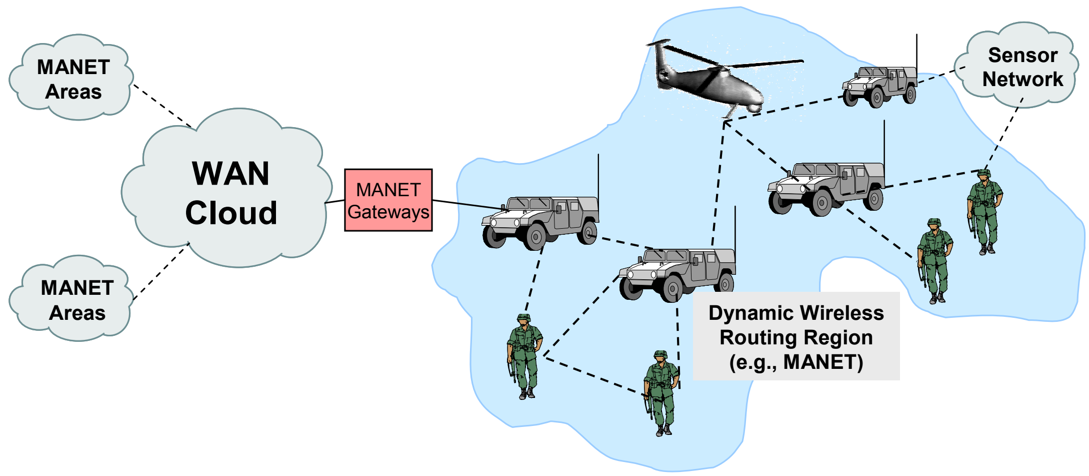

Figure 2-b: "Last Mile" Dynamic Wireless Routing Example

As depicted in Figure 2-b dynamic wireless routing based upon MANET technology is intended to solve more localized topological dynamics --not always due to mobility-- within network architectures. As mentioned, in the military network sense, the functionality mainly addresses the needs of the “last mile tactical wireless problem”. A broad range of early research and dynamic wireless routing prototype specifications have been developed over the last ten years to address this problem area. Basic concepts began as early a the 1970s with DARPA sponsored "packet radio" research, yet a new flurry of design activity and research advances have occurred in the last 10 years [8]. The wide availability of both cheap network computing devices and embedded broadband wireless technology has spawned this more recent interest and activity in developing self-organizing networks. In addition, an IP-based open standards effort for routing of mobile ad-hoc networking (MANET) is evolving within the Internet Engineering Task Force (IETF) for supporting both IPv4 and IPv6 networking [9]. Evolving IETF MANET specifications fundamentally provide improved operational IP routing performance for dynamic, wireless routing regions. These specifications are presently evolving with extensible design frameworks and operating parameters that may be adjusted for particular scenarios of deployment. The variety of anticipated military scenarios and uses require analysis and design consideration beyond the basic default specifications. This is especially true when considering cross layer aspects of the both system design and integration as will be discussed later.

As mentioned, MANET technology is applicable in stressed wireless tactical environments experiencing mobility or increased topological dynamics, but the tradeoffs between classes of approaches for particular scenarios and platform requirements need to be carefully considered. As an example, the basic technology area --dynamic wireless routing-- is potentially applicable for grid networks and self-organizing sensor networks. The NRL Scalable Reconfigurable Sensor Networks (SRSS) project has demonstrated prototypes of future generation sensor platforms using open standard MANET technology and acting as an integral part of an advanced, self-organizing hybrid network. We have also examined heterogeneous operation within hybrid mobile grid networks in which a set of router nodes are preferred or advantaged in terms of resources or location. In general, MANET approaches are intended to be relatively lightweight in nature and suitable for heterogeneous adaptation across multiple hardware and wireless environments. Design specification for MANET is often amenable to lightweight implementation and can be adapted on limited capability embedded systems as needed. It is also understood that not all future sensor network devices will be sophisticated enough to run a network kernel or sophisticated routing algorithms. Non-sophisticated devices or networks can still be integrated but appear as "locally attached" or "end applications" within an overall IP-based MANET network architecture.

Although envisioned as solving "last mile" network problems, MANET technology can also improve backbone or WAN interconnections wherever wireless dynamics caused by movement or environmental effects are expected. As an example, recent design efforts have begun within the IETF to extend MANET capability to present existing backbone router specifications such as Open Shortest Path First (OSPF) version 3. A design goal of this protocol is to support IPv6 operations and provide a simplified extension to present deployed protocols. This should improve transition potential in military backbone systems presently deploying and operating OSPF-based systems.

IP-based Edge Mobility Technology

Edge mobility technology, a second major area of mobile networking we will be discussing is depicted Figure 2-c.

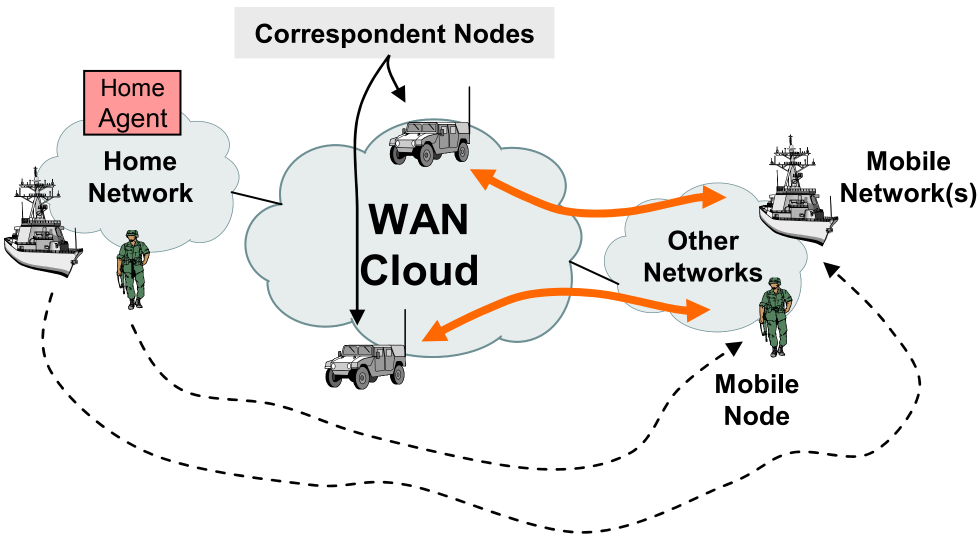

Figure 2-c: IP-Based Edge Mobility Examples

Edge mobility technology and related protocols provide solutions for mobile users, systems, or even entire mobile networks that roam within a larger wide area network (WAN) architecture. Some edge mobility technologies being developed within the IP standardization community include mobile IPv6 (MIPv6), designed to support individual roaming mobile hosts, and network mobility (NEMO) protocols, designed to support roaming aggregate networks. Both technologies largely hinge on the concept of a supporting home agent (HA). The HA serves as an identity and tracking anchor point for roaming nodes or networks within a larger network under the assumption that these nodes wish to retain their home-based associations and addresses. This is often useful if the roaming or network contains distributed server functionality that needs to maintain identity via its "well-known" or "home" address(es) or if there are active end-to-end connections that must be maintained while roaming. When end system address identification while roaming is required “pure routing” solutions do not generally scale when deployed at the WAN architectural level.

Due to space limitations, we do not provide a completely comprehensive treatment of mobile architecture issues but we have presented some key differences between routing and edge mobility solutions. Overall, technologies in these two areas can be adapted to solve differing architectural problems to improve future networking flexibility and robustness. We will now discuss several evolving technologies in these areas and testing methods being adopted for analysis.

MOBILE AD HOC ROUTING AND TEST METHODS

In the recent past, there have been limited software tools and methodologies that specifically address mobile network analysis and assessment. Analyzing network mobility technology requires specialized investigative work and test methods to produce meaningful performance assessments and recommendations. One of the significant results of recent mobile networking research activity is the establishment of methods and tools to improve analysis of protocol performance and behavior. Historically, mobile routing evaluation has mainly concentrated on simulation environments. Field testing and emulation on working hardware has been difficult and expensive to perform. Despite abstraction issues simulation is often the appropriate evaluation environment from moderate to large scale sized network simulations (> 50 node networks). Smaller size mobile networks field tests are achievable but require structured test methods and strategies to collect and process meaningful results. Yet, because of the expense and difficulty of controlling and repeating field tests, mobile emulation test methods are valuable to help bridge the cost and knowledge gap between simulation and field testing. At NRL, we have developed and applied specialized test procedures, data collection, post analysis, and visualization tools to support unique requirements of mobile network testing and analysis. Also by adopting a software cross-platform development strategy for prototype network code, the same set of traffic tools, visualization tools, protocol implementations, and post analysis methods can be used in simulation, emulation, and field testing. These test tools have been used in numerous mobile ad hoc field tests to produce, visualize, and post analyze network traffic and conditions. The procedures and tools have also been reused within emulation and simulation environments providing better test consistency and cross validation.

An example of how the US-designed Mobile Network Emulator (MNE) [4] has been adapted to support controlled, repeatable MANET experimentation is shown in Figure 3-a.

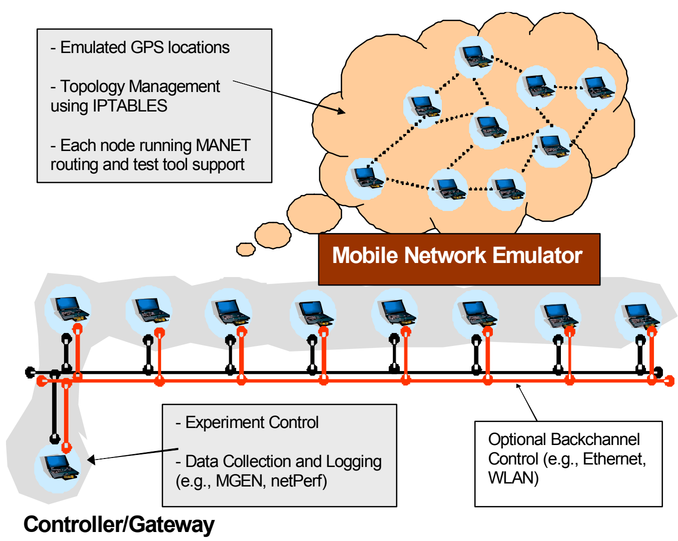

Figure 3-a: NRL Mobile Network Emulator

Figure 3-a illustrates 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. As an example, early OLSR-based field trials were executed within the INSC [3] and in some cases mobility traces were recorded

and used later to drive the mobility patterns within emulation tests with the same traffic patterns. Figure 3-b shows an example output from NRL test traffic, mobile emulation, and post analysis tools. This type of network analysis can also be performed in real time as well.

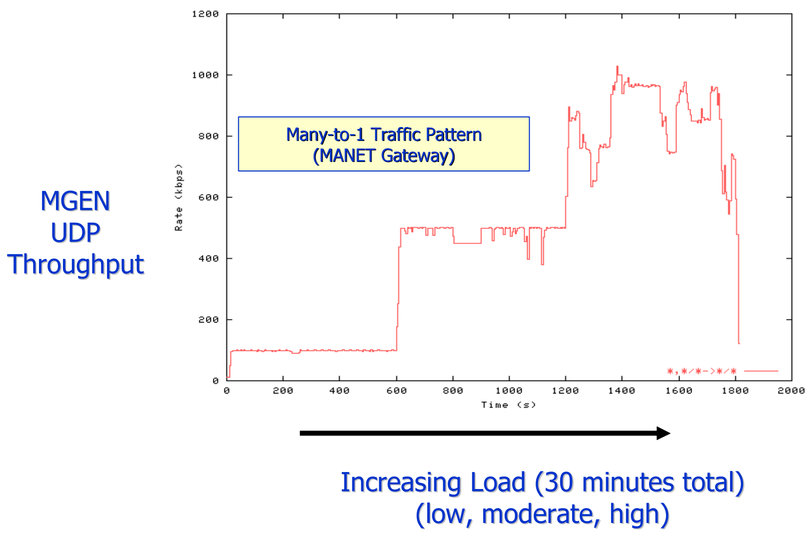

Figure 3-b: Example Mobility Scenario Post Analysis Results

EMERGING MOBILE AD HOC MULTICAST CAPABILITY

The development of a multicast capability for ad hoc networks is an especially important innovation for future military applications, because of a mission emphasis on group-centric communication and collaboration. MANET-oriented multicast routing will provide a more effective means for both end user communications and distributed network control. Previous MANET unicast routing work often includes an efficient data flooding capability within the routing application layer (e.g., router discovery, proactive link state dissemination). Optimizing the flooding process by minimizing and maintaining efficient relay node sets within a dynamic wireless topology is often a key design factor. An evolving protocol specification development effort for a simplified multicast forwarding mechanism is being planned within the IETF MANET WG and will be based upon the concept of optimizing and maintaining relay sets within a MANET routing area. This forwarding mechanism will be designed to forward generic user data (e.g., video streams, multicast chat) within MANET environments and will provide a significantly enhanced forwarding capability. This capability may also open up new methods for autoconfiguring and managing distributed, dynamic systems.

At NRL we have developed some early prototypes of simplified multicast forwarding in MANET and are testing performance and design tradeoffs in both simulation and emulation [1]. Fig 4-a, shows an example performance curve measuring max achievable multicast goodput across a variety of topologies using actual working prototype code within the NRL mobile network emulator (MNE). The main result demonstrates the significant improvement in goodput achieved against a technique that uses a classical flooding scheme. In denser topologies (MCDS 2 &1), the improvements become more significant achieving often 3 or more times the overall goodput. Improvements are also expected to be greater in larger topologies beyond this simple 10 node experiment and evaluation that was performed on working hardware within the NRL MNE system.

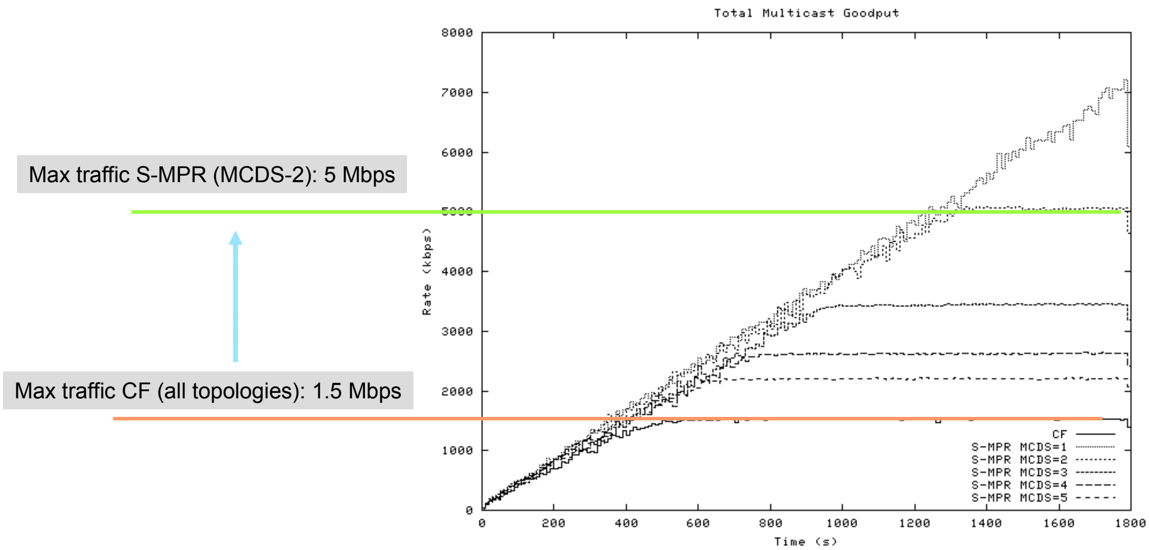

Figure 4-a: Mobile Ad Hoc Multicast Forwarding Results in Differing Topologies

CROSSLAYER PERFORMANCE AND DESIGN ISSUES

Traditional Internet wired protocol design assumptions and mechanisms (e.g., address assignment, gateway discovery, and service discovery) are not always suitable in MANET environments due to wireless interface behavior and dynamic, multi-hop configuration requirements. Several issues to be addressed include the evolving development of service discovery, address autoconfiguration, protocol coordination mechanisms in distributed wireless environments. While these mechanisms can be designed in a layered manner, it is clear that overall performance considerations are not orthogonal to the design and interaction with other layers (e.g., routing, MAC, middleware). The appropriate mechanisms are also not orthogonal to the intended application or deployment scenario of the mobile ad hoc system. Figure 5-a depicts a classic layered view and some issues that are involved in the overall design and operation of mobile ad hoc systems.

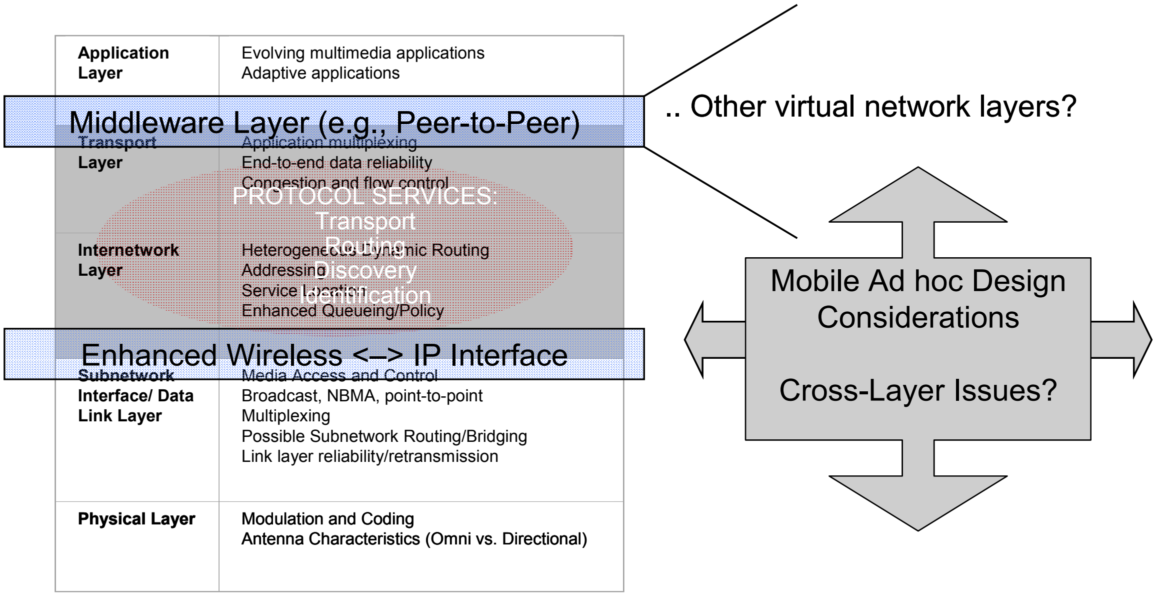

Figure 5-a: Cross Layering Design issues and Considerations

A known limiting design factor in MANET --and more generally a problem with all strictly layered network protocols used over dynamic wireless channels-- is the local interface and neighbor sensing process. The process is generally assumed to be a relatively simple one (e.g., UP/DOWN) within wired network designs. There is often periodic injection of added signaling traffic to detect neighbors and over wireless there are often gross inaccuracies of judging link quality based on this injected traffic using timeouts. Links and neighbors can be lost because of motion, wireless effects, or even network congestion. The reliance on this network layer detection and signaling traffic could be relaxed and the robustness of protocol maintenance could be improved if some cross layering information is provided between lower layers and the routing layer. As an example, a promising future improvement of MANET designs would be the ability to obtain a list of neighbors, link quality metrics, etc. from the link layer, and use this information to make better routing and neighbor maintenance decisions more robustly and with more fidelity. Unfortunately, there is no standard way to get and subsequently interpret such information from wireless network interface drivers. Link layer feedback could also be very useful in edge mobility technology (e.g., MIPv6 and NEMO). There is also significant added signaling overhead used for the purpose of detection of node motion if fast switching is desired. With link layer feedback or triggers, it is possible to improve detection of when a node is moving from one network to the other or to better track and manage quality of neighbor network links.

Specific radio technologies can also have a great effect on wireless mobility technology. Bandwidth capacities, propagation delay times, etc. can all affect the feasibility of different mobility solutions. These radio effects must all be taken into account when deciding on a specific mobility solution for a given scenario. There are strong debates and opinions within the community regarding how much cross layering should be used within wireless network architectures [7], but interest is growing in developing more common approaches. The authors' viewpoint is that a Internet-type general layering approach should still be preserved for interoperability and heterogeneous flexibility within network stacks. However, cross layering interfaces should be pursued and better understand in cases where they have significant performance impact. Previous examples of neighbor discovery and link quality tracking are areas that could greatly improve mobile ad hoc network routing and management schemes.

CONCLUSION AND ACKNOWLEDGEMENTS

We have presented a number of key issues and considerations relating to evolving mobile network architecture design and integration. A rough taxonomy of overall mobile architecture design and various evolving technology components was outlined. Dynamic wireless routing and edge mobility are two areas we presented as ongoing areas of R&D important to consider in future architectures. More specifically mobile ad hoc network (MANET) routing, Mobile IP, and network mobility were discussed along with IPv6 capable variants of these components. Mobile networking requires new ways of approaching and analyzing network behavior and performance. An overview of prototype test tools and procedures were provided and we feel this has been an invaluable contribution given the large set of ad hoc networking designs and scenarios often requiring evaluation and testing. An overview of more recent multicast forwarding progress and results were summarized and further work in this area will be taking place this year. We concluded with a short summary of some cross layering design and performance issues that need additional consideration and future focus within mobile network environments.

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