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Mobile Ad hoc Networking (MANET): Routing Protocol Performance Issues and Evaluation Considerations

Status of this Memo

Summary

This memo describes the concept of mobile ad hoc networking--giving a rationale for its existence and outlining the unique issues and challenges found in this form of purely wireless, mobile networking.

1. Introduction

With recent performance advancements in computer and wireless communications technologies, advanced mobile wireless computing is expected to see increasingly widespread use and application, much of which will involve the use of the Internet Protocol (IP) suite. The vision of mobile ad hoc networking is to support robust and efficient operation in mobile wireless networks by incorporating routing functionality into mobile nodes. Such networks are envisioned to have dynamic, sometimes rapidly-changing, random, multihop topologies which are likely composed of relatively bandwidth-constrained wireless links.

Within the Internet community, routing support for mobile hosts is presently being formulated as "mobile IP" technology. This is a technology to support nomadic host "roaming", where a roaming host may be connected through various means to the Internet other than its well known fixed-address domain space. The host may be directly physically connected to the fixed network on a foreign subnet, or be connected via a wireless link, dial-up line, etc. Supporting this form of host mobility (or nomadicity) requires address management, protocol interoperability enhancements and the like, but core network functions such as hop-by-hop routing still presently rely upon pre-existing routing protocols operating within the fixed network. In contrast, the goal of mobile ad hoc networking is to extend mobility into the realm of autonomous, mobile, wireless domains, where the nodes themselves form the network routing infrastructure in an ad hoc fashion.

This memo first describes the characteristics of Mobile Ad hoc Networks (MANETs), and their idiosyncrasies with respect to traditional, hardwired packet networks. It then discusses the effect these differences have on the design and evaluation of network control protocols with an emphasis on routing.

2. Applications

The technology of Mobile Ad hoc Networking is somewhat synonomous with Mobile Packet Radio Networking (a term coined via during early military research in the 70's and 80's), Mobile Mesh Networking (a term that appeared in an article in The Economist regarding the structure of future military networks) and Mobile, Multihop, Wireless Networking (perhaps the most accurate term, although a bit cumbersome).

There is current and future need for dynamic ad hoc networking technology. The emerging field of mobile and nomadic computing, with its current emphasis on mobile IP operation, should gradually broaden and require highly adaptive mobile networking technology to effectively manage multihop, ad hoc network clusters which can operate autonomously or, more than likely, be attached at some point(s) to the fixed Internet.

Some applications of MANET technology could include industrial and commercial applications involving cooperative mobile data exchange.

In addition, mesh-based mobile networks can be operated as robust, inexpensive alternatives or enhancements to cell-based mobile network infrastructures. There are also existing and future military networking requirements for robust, IP-compliant data services within mobile wireless communication networks [1]--many of these networks consist of highly-dynamic autonomous topology segments. Also, the

developing technologies of "wearable" computing and communications may provide applications for MANET technology. When properly combined with satellite-based information delivery, MANET technology can provide an extremely flexible method for establishing communications for fire/safety/rescue operations or other scenarios requiring rapidly-deployable communications with survivable, efficient dynamic networking. There are likely other applications for MANET technology which are not presently realized or envisioned by the authors. It is, simply put, efficient IP-based routing technology for highly dynamic, autonomous wireless networks.

3. Characteristics of MANETs

A MANET consists of mobile platforms (combined router, host and wireless communications platforms)--herein simply referred to as "nodes"--which are free to move about arbitrarily. The nodes may be located in or on airplanes, ships, trucks, cars, perhaps even on people, and there may be multiple hosts per router. A MANET is an autonomous system of mobile nodes. The system may operate in isolation, or may have gateways to and interface with a fixed network--typically envisioned to operate as a stub network connecting to a fixed internetwork.

The nodes are equipped with wireless transmitters and receivers using antennas which may be omnidirectional (broadcast), highly-directional (point-to-point) or some combination thereof. At a given point in time, depending on the nodes' positions and their transmitter and receiver coverage patterns, transmission power levels and cochannel interference levels, a wireless connectivity in the form of a random, multihop graph or "ad hoc" network exists between the nodes. This ad hoc topology may change with time as the nodes move or adjust their transmission and reception parameters.

MANETs have several salient characteristics:

1) Dynamic topologies: Nodes are free to move arbitrarily; thus, the network topology--which is typically multihop--may change randomly and rapidly at unpredictable times, and may consist of both bidirectional and unidirectional links.

2) Bandwidth-constrained, variable capacity links: Wireless links will continue to have significantly lower capacity than their hardwired counterparts. In addition, the realized throughput of wireless communications--after accounting for the effects of multiple access, fading, noise, and interference conditions, etc.--is often very much less than a radio's maximum transmission rate.

One effect of the relatively low to moderate link capacities is that congestion is typically the norm rather than the exception, i.e. aggregate application demand will likely approach or exceed network capacity frequently. As the mobile network is often simply an extension of the fixed network infrastructure, mobile ad hoc users will demand similar services. These demands will continue to increase as multimedia computing and collaborative networking applications rise.

3) Power-constrained operation: Some or all of the nodes in a MANET may rely on batteries for their energy. For these nodes, the most important system design criteria for optimization may be power conservation.

4) Limited physical security: Mobile wireless networks are generally more prone to physical security threats than are fixed-cable nets. The increased possibility of eavesdropping, spoofing, and denial of service attacks should be carefully considered. Existing link security techniques are often applied within wireless network to reduce security threats. As a benefit, the decentralized nature of network control in MANETs provides additional robustness against single points of failure of more centralized approaches.

In addition, some envisioned networks (e.g. mobile military networks or highway networks) may be relatively large (e.g. tens or hundreds of nodes per routing area). The need for scalability is not unique to MANETS. However, in light of the preceding characteristics, the mechanisms required to achieve scalability likely are.

These characteristics create a set of underlying assumptions and performance concerns for protocol design which extend beyond those guiding the design of routing within the higher-speed, semi-static topology of the fixed Internet.

4. Goals of IETF Mobile Ad Hoc Network (manet) Working Group

The intent of the newly formed IETF manet working group is to develop a peer-to-peer mobile routing capability in a purely mobile, wireless domain. This capability will exist beyond the fixed network (as supported by traditional IP networking) and beyond the one-hop fringe of the fixed network.

The near-term goal of the manet working group is to standardize an intra-domain unicast routing protocol which:

* provides a mode(s) of operation for effective operation in a mobile networking "context". (a context is a set of defined

networking characteristics),

* provides a standard "mode discovery" protocol so that newly-arriving nodes may learn the mode in which a given MANET is operating,

* supports traditional, connectionless IP service,

* reacts efficiently to topological changes while maintaining effective routing in a mobile networking context.

The working group will also address issues pertaining to security and interaction/interface with link-layer protocols and internet security protocols. In the longer term, the group may look at the issues of layering more advanced mobility services on top of the initial unicast routing developed. These longer term issues will likely include investigating multicast and QoS extensions for a dynamic, mobile area.

5. Why an IP-Layer Routing Solution?

A solution at the IP layer can provide a benefit similar to the intention of the original Internet, viz. "an interoperable internetworking capability over a heterogeneous networking infrastructure". In this case, the infrastructure is wireless, rather than hardwired, consisting of multiple wireless technologies, channel access protocols, etc. Improved IP routing and related networking services provide the glue to preserve the integrity of the mobile internetwork segment in this more dynamic environment.

6. MANET Routing Protocol Performance Issues

To judge the merit of a routing protocol, one needs metrics--both qualitative and quantitative--with which to measure its suitability and performance. These metrics should be somewhat *independent* of any given routing protocol.

The following is a list of desirable qualitative properties:

1) Distributed operation: This is an essential property, but it should be stated nonetheless.

2) Loop-freedom: Not required per se in light of certain quantitative measures (performance criteria), but generally desirable to avoid problems such as worst-case phenomena, e.g. a small fraction of packets spinning around in the network for arbitrary time periods. Ad hoc solutions such as TTL values can bound the problem, but a more structured and well-formed approach

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is generally desirable as it oftentimes leads to better overall performance.

3) Demand-based operation: Instead of assuming uniform traffic distribution within the network (and maintaining routing between all nodes at all times), let the routing algorithm adapt to the traffic pattern on a demand or need basis. If this is done intelligently, it will utilize network resources more efficiently.

4) Unidirectional link support: Bidirectional links are typically

assumed in the design of routing algorithms, and many algorithms are incapable of functioning properly over unidirectional links. Nevertheless, unidirectional links can and do occur in wireless networks. Often times, a sufficient number of duplex links exist so that usage of unidirectional links is of limited added value. However, in situations where a pair of unidirectional links (in opposite directions) form the *only* bidirectional connection between two ad hoc clusters, the ability to make use of them is invaluable.

5) Security: Without some form of network-level security or link layer security, a MANET routing protocol is vulnerable to many forms of attack. It may be relatively simple to snoop network traffic, replay transmissions, manipulate packet headers, and redirect routing messages, within a wireless network without appropriate security provisions. While these concerns exist within wired infrastructures and routing protocols as well, maintaining the "physical" security of of the transmission media is harder in practice with MANETs. Sufficient security protection to prohibit distruption of modification of protocol operation is desired. This may be somewhat orthogonal to any particular routing protocol approach, e.g. through the application of IP Security techniques.

6) "Sleep" period operation: As a result of power conservation, or some other need to be inactive, nodes of a MANET may stop transmitting and/or receiving (even receiving requires power) for arbitrary time periods. A routing protocol should be able to accomodate such sleep periods without overly adverse consequences. This property may require close coupling with the link layer protocol through a standardized interface.

The following is a list of quantitative metrics that can be used to assess the performance of any routing protocol.

1) End-to-end data throughput and delay: Statistical measures of data routing performance (e.g., means, variances, distributions) are important. These are the measures of a routing policy's

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effectiveness--how well it does its job--as measured from the *external* perspective of other policies that make use of routing.

2) Efficiency: If data routing effectiveness is the external measure of a policy's performance, efficiency is the *internal* measure of its effectiveness. To achieve a given level of data routing performance, two different policies may expend differing amounts of overhead, depending on their internal efficiency. Protocol efficiency may or may not directly affect data routing performance. If control and data traffic must share the same channel, and the channel's capacity is limited, then excessive control traffic may impact data routing performance.

It is useful to track two ratios that illuminate the *internal* efficiency of a protocol in doing its job (there may be others that the authors have not considered):

* Average number of data bits transmitted/data bit delivered--this can be thought of as a measure of the efficiency of delivering data within the network.

* Average number of control bits transmitted/data bit delivered--this measures the efficiency of the protocol in expending control overhead to delivery data packets. Note that this should include not only the bits in the routing control packets, but also the bits in the header of the data packets. In other words, anything that is not data is control overhead, and should be counted in the control portion of the algorithm.

Also, we must consider the networking *context* in which a protocol's performance is measured. Essential parameters that should be varied include:

1) Network size--measured in the number of nodes

2) Network connectivity--the average degree of a node (i.e. the average number of neighbors of a node)

3) Topological rate of change--the speed with which a network's topology is changing

4) Link capacity--effective link speed measured in bits/second, after accounting for losses due to multiple access, coding, framing, etc.

5) Fraction of unidirectional links--how effectively does a protocol perform as a function of the presence of unidirectional links?

6) Traffic patterns--how effective is a protocol in adapting to non-uniform or bursty traffic patterns?

7) Mobility--when, and under what circumstances, is temporal and spatial topological correlation relevant to the performance of a routing protocol? In these cases, what is the most appropriate model for simulating node mobility in a MANET?

8) Fraction and frequency of sleeping nodes--how does a protocol perform in the presence of sleeping and awakening nodes?

A MANET protocol should function effectively over a wide range of networking contexts--from small, collaborative, ad hoc groups to larger mobile, multihop networks. The preceding discussion of characteristics and evaluation metrics somewhat differentiate MANETs from traditional, hardwired, multihop networks. The wireless networking environment is one of scarcity rather than abundance, wherein bandwidth is relatively limited, and energy may be as well.

In summary, the networking opportunities for MANETs are intriguing and the engineering tradeoffs are many and challenging. A diverse set of performance issues requires new protocols for network control. A question which arises is "how should the *goodness* of a policy be measured?". To help answer that, we proposed here an outline of protocol evaluation issues that highlight performance metrics that can help promote meaningful comparisons and assessments of protocol performance. It should be recognized that a routing protocol tends to be well-suited for particular network contexts, and less well-suited for others. In putting forth a description of a protocol, both its *advantages* and *limitations* should be mentioned so that the appropriate networking context(s) for its usage can be identified. These attributes of a protocol can typically be expressed *qualitatively*, e.g., whether the protocol can or cannot support shortest-path routing. Qualitative descriptions of this nature permit broad classification of protocols, and form a basis for more detailed *quantitative* assessments of protocol performance. In future documents, the group may put forth candidate recommendations regarding protocol design for MANETs. The metrics and the philosophy presented within this document are expected to continue to evolve as MANET technology and efforts mature.

6. References

[1] B. Adamson, "Tactical Radio Frequency Communication Requirements for IPng," RFC 1677, Aug. 1994.

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