Implementation of Mobile and Wireless Adhoc Networks with Multi-Hop Data Routing Capabilities

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Abstract

Wireless networking allows mobile users access to a broad range of information and services while on the move. The cost of a wireless network is a function of the number of base stations in the network. The wireless *adhoc wireless networks* is and emerging technology. These networks substantially reduce the installation cost of networks because these networks do not require infrastructure. However, each mobile terminal has to work as a host as well as router. This work concentrates on the problem of adding multi-hop capabilities to the existing adhoc network platforms such as the IEEE 802.11b. Real-time experimental set up is created and multi-hop ad hoc network capabilities are investigated.

I. Introduction

The phenomenal growth of the Internet and online services is a strong testimony to the benefits of sharing data and resources. To day the modern business relies heavily on the computer networks. During the past decade the wireless communications has spread its wings over all the countries of the world. A wireless network consists of mobile devices, which communicate while on the move. The number of subscribers to wireless communications has exceeded one billion. The number is still growing. To provide wireless services, large wireless networks have been installed.

The wireless LANs allow users access to information data basis without looking for connection points. The network managers can set up or augment networks without installing or moving wires. Generally the wireless networks provide the final few meters of connectivity between mobile users and wired network. Wireless LANs offer productivity, convenience, and cost advantages over traditional wired networks. The merits of Wireless LANs also include: mobility, faster installation speed, simplicity, installation flexibility, reduced cost-of-ownership, and scalability among others.

The power and flexibility of wireless LANs has found very extensive list of applications. For example, the university students can use the wireless connectivity to get access to libraries and information databases. The doctors are able to increase their productivity by getting instant access to patients' health and previous prescriptions. Consulting or accounting audit teams or small workgroups increase productivity with quick network setup. Soldiers in the front-line share can intelligence information between them and with the central base.

Remote-site workers e.g. in oil companies can use wireless network access to exchange oil well data with their base company.

Network managers implement wireless LANs to provide backup for mission-critical applications running on wired networks.

All these applications require substantial infrastructure and investment. The need to increase the capacity without using additional spectrum requires that the cell size be as small as possible and the terminal be of low power. These two requirements result in very large number of base stations and expensive network infrastructure. Alternative to this are networks that do not require infrastructure. Multi-hop packet networking is one possibility. Out of the currently available technologies, Bluetooth and IEEE 802.11b can be used in single-hop ad hoc networks, where each node acts as a host only. IEEE 802.11 defines the standards for establishment of such networks. The IEEE 802.11 network operates in two modes - infrastructure networks and Ad hoc or on-demand networks.

In ***Infrastructure Networks***, mobile nodes communicate via access points or base stations, which are connected to a fixed wired network. The mobile devices are free to roam anywhere without loosing communications with other devices on the network provided these remain within range of an access point. When the mobile terminal moves from the coverage area of one access point to another, handover similar to that exists in the cellular systems occurs. Wi-Fi (802.11 compliant) products are generally interoperable. With careful placements of access points in various strategic locations, an enterprise-wide Wireless Local Area Networking (WLAN) is achieved. IEEE 802.11a defines the standard for the infrastructure WLAN mode. Applications of these networks include college and university campuses, hospitals, factories, front-line military communications, communications between remote-site workers (like oil exploration workers) and their company base etc.

An ***Ad hoc (or infrastructure-less) Network*** on the other hand is a network entirely *'on the fly'*, created dynamically without any pre-determined network organization – a reason why these are sometimes known as self-organizing networks. In these networks, each and every node is able to communicate on a peer-to-peer basis provided these are within the radio coverage of each other. As each node in a single-hop ad hoc network can only act as 'host', all nodes must be within range of each other. IEEE 802.11b defines the standard for the Ad hoc WLAN modes. Current products like IEEE 802.11b wireless cards and Bluetooth devices can form ad hoc networks but with the limitation that only single-hop networks can be formed.

In a multi-hop ad hoc network however, all nodes will act as hosts and as well as routers – making data exchanges between nodes that are not within transmission range of each other possible via multi-hop routing. Mobile x86 series PCs were used to form a multi-hop ad hoc network with 802.11b wireless network cards. The behavior of the network is then studied as the mobile nodes randomly move about within the wireless coverage.

II. Contending Wireless Network Standards

A. Mobile IP

The use of the Internet Protocol (IP version 4) has been suggested in wireless networking. Mobile IP focuses on the Network Layer. In this protocol, the IP address of the mobile machine does not change when it moves from a home to a visitor network. In order to maintain a live link between a mobile node and the network, a forwarding routine is implemented. Whenever a mobile agent moves from its home to a visited network, it registers itself with the foreign agent of the visited network. The mobile instructs its home agent to forward (tunnel) packets addressed to it via the foreign agent. The forward agent then sends the packets to the mobile agent. When the mobile agent returns to its original network, it informs both agents (home and foreign) that the original configuration has been restored. No one on the outside networks need to know that the mobile agent moved. Mobile IP has potentials for both LAN and MAN roaming. This configuration works, but it has a drawback of keeping storing and forwarding capabilities while the mobile agent is on neither the home nor the foreign network. In addition, Mobile IP works only for IPv4 and does not take advantage of the features of the newer IPv6.

B. IEEE 802.11 Standard

In the IEEE's standard for wireless networks (802.11), there are two possible network configurations - with infrastructure and without (ad-hoc). In the ad-hoc network, computers are brought together to form a network "on the fly." As shown in Figure 1, there is no structure to the network; there are no fixed points; no centralized server; no administration or pre-configuration; and usually every node is able to communicate with every other node. A good example of this is a business meeting where employees bring laptop computers together to communicate and share design or financial information.

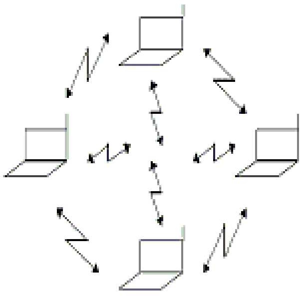

Figure 1: Wireless Ad hoc Network

The second type of network requires infrastructure shown in Figure 2.

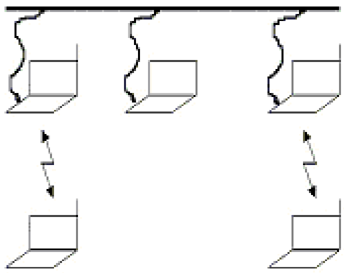

Figure 2: Wireless Infrastructure Network

This architecture uses fixed network access points to the mobiles. These network access points are usually connected to landlines to widen the LAN's capability by bridging nodes to other wired nodes. If the service areas overlap, handoffs of mobiles from one access point to the other will occur. This structure is very similar to the present day cellular networks.

C. Bluetooth

Bluetooth, a wireless interconnect standard, was designed by a consortium of experts from Ericsson, IBM, Intel, Nokia and Toshiba. The technology promises fast, secure, point-to-point wireless communications over relatively short distances (approximately 10 meters) for devices as diverse as mobile phones, consumer electronics appliances and desktop computers. Under this standard, products will be able to link to one another using spectrum in the unlicensed 2.4 GHz ISM band. Fast frequency-hopping

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technique has been proposed to minimize interference from non-Bluetooth sources. In addition to defining a hardware standard, Bluetooth defines a protocol stack that allows for hierarchical ad hoc networking. Also, the Bluetooth specifications have some features to allow users to access the Internet through a mobile phone or a wired analog or digital connection like the public switched telephone network (PSTN) or an ISDN line. Although Bluetooth has been standardized for some time, the devices are just beginning to become available. However, like 802.11, the currently available Bluetooth devices are only single-hop devices – that allow for example downloading e-mail messages from a server machine to a wireless hand-held device, without a multi-hop data transfer capability.

A major drawback of the Bluetooth lies in its inability to support Internet Protocol (IP). Also, while other standards, like 802.11b, are designed for wide-reaching applications, Bluetooth does not have the necessary bandwidth to handle full network demands, and is not designed for full WAN connectivity. It is being proposed that these devices should be allowed to operate in frequencies outside the ISM bands.

D. HiperLAN 1 and 2

While 802.11 has captured a good degree of attention, the European Telecommunications Standards Institute (ETSI) has been working on high-throughput WLAN technologies under its Broadband Radio Access Networks (BRAN) project. The most notable developments include the High-Performance Radio LAN (HIPERLAN) 1 and 2 standards, which have nominal throughput in the 24 Mbps range.

HiperLAN/1 is based on a distributed-control architecture that extends the peer-to-peer model to include forwarding on the order of a distributed router. While the possibility that network backhaul may interfere with user traffic is introduced in this case, the flexibility allowed by the resulting arbitrary mesh structures can be advantageous in many deployment scenarios.

HiperLAN/2 has many characteristics in common with 802.11a. The original mission of HiperLAN/2 was to be a form of wireless ATM, but the final standard is likely to interoperate with a broad range of wired technologies. It is expected that some harmonization of the two specifications will take place, perhaps resulting in a single unified specification over time.

III. Wireless Ad hoc Network with Multi-hop Data Transfer Capabilities

Based on the discussion above, several critical issues involving the future deployments of wireless multi-hop ad hoc networks are addressed. In a ***Multi-hop Ad hoc networks***, all nodes act as hosts and as well as routers. Thus, communication among nodes that are not within the coverage each other is possible via multi-hop data routing. The network topology and routing changes dynamically as the terminals move about. The resulting dynamic multi-hop topologies present many challenges for Media Access Control (MAC) and reliable transport protocol designers. For example, since all nodes in an ad hoc multi-hop network behave like routers, routes to other nodes in the network must be discovered and maintained dynamically. In addition, the propagation characteristics between the hosts present another challenge. Many routing protocols and media access control techniques as well as efficient fading combatant schemes that meet these challenges have been proposed.

This work concentrates on the problem of adding multi-hop capabilities to existing ad hoc network platforms such as the IEEE 802.11b. The behavior of the network as the nodes randomly move is then studied. IEEE 802.11b is a wireless LAN standard that operates in the 2.4 GHz unlicensed ISM band, at a data rate of 1 to 11 Mbps and distances of 25 to 550 meters. This mode allows nodes to form an ad hoc network, but the communication is limited to single-hop, with no multi-hop capabilities. Since the IEEE 802.11 standard only defines the host-to-network layer, multi-hop data transfer capabilities can be incorporated at the upper layer protocols.

IV. Experimental Setup and Tested Topologies

Real-time experimental set up is used to investigate the implementation of a multi-hop ad hoc network using the 802.11b wireless LAN cards. A multi-hop data routing protocol implemented at the IP layer of the TCP/IP protocol stack was used for the multi-hop data transfer and self-organization of the network under terminal mobility. The experimental setup consists of five x86 series PCs, one of them running Windows while others four run Linux operating system.

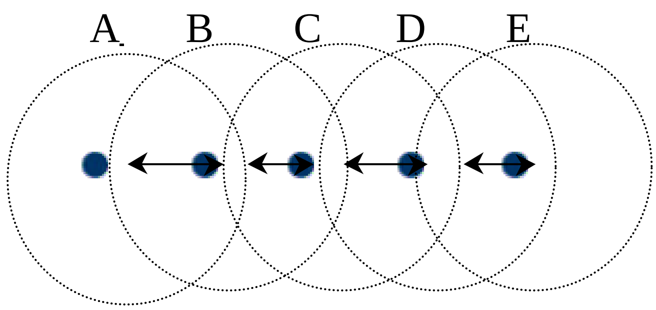

Figure 3: Experimental Topology I

The Dynamic Source Routing (DSR) protocol was used for data routing and organization of the network, as nodes randomly move about. Figures 4 and 5 show some of the tested network topologies. For each of the tested topologies and the transitions between them, the network was able to adapt and reconfigure itself to the changes in

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topology. The tests were conducted both in open-office and closed-office environments with nodes moving at walking speed. Communications were established in both cases using basic communication applications like 'ping' and 'telnet' as well as some sample data transfers. Nodes running Windows and Linux intercommunicate perfectly well.

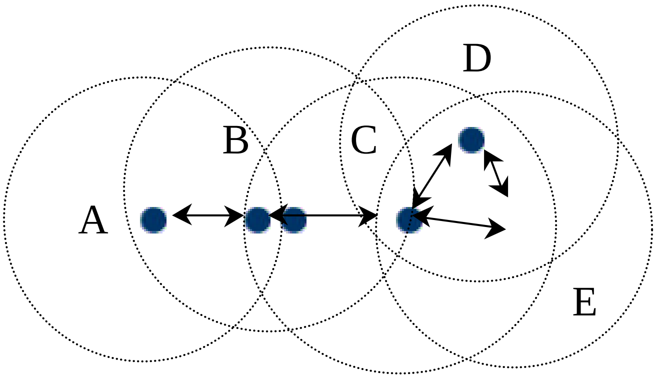

Figure 4: Experimental Topology II

KEY:

A, B, C, D, E -Five Wireless nodes.

-Direction of communication established.

-Area of Coverage (range) for each node.

B. Issues and Discussions

From the observations of this study, various issues are identified as critical in the future deployments of wireless LANs and are discussed below:

1. Hidden Node Effect and Channel Capture:

In the topology of figure 4, we observe that node A can communicate with node B and node B can communicate with node C, but nodes A and C cannot intercommunicate. Hence they are 'hidden' from one another. Therefore, although node A may sense the channel to be clear in order to communicate with node B, node C may in fact be communicating with node B, and an attempt by node A to send packet to node B at that time will result in receiver-side collision and then the connection with the stronger SNR wins the contention. Though IEEE 802.11 has some procedures that reduce the problem of 'hidden node' effect considerably, connections with long delays will still experience this problem. This is because the necessary handshake signals are received late in such situations and link conditions changes rapidly due to the dynamic nature of the network. Another important problem we observed in our setup is that of channel capture. This occur in the test of figure 5 where nodes C, D, and E were enclosed in the same room, and nodes A and B roam about at different locations outside the room to ensure differential SNR levels at the desired reference node. Node C was made a case study. As can be observed from the figure, at node C, connection to node D has the highest SNR, followed by that to node E and then the connection to node B has the smallest SNR. Also, node B can view and communicates directly with node C, while nodes D and E can at the same time view and communicate directly with node C. However, node B can neither communicate directly with node D or E (Hidden nodes), except via multi-hop data transfer. There were simultaneous attempts by nodes B, D and E to communicate with node C. It is observed that node D wins the contention. This was repeated several times and each time, node D always wins – thus capturing the channel permanently. We conclude that IEEE 802.11 networks will always exhibit channel capture in the presence of hidden terminals when the SNR of contending connections differ –even when the difference is marginal.

2. Fading:

The presence of fading in several forms is another critical issue. This must be addressed effectively for successful deployments of Wireless LANs. A communication between a source and a destination node will fail to establish if either the source or the destination node or both are located inside a deep fading region. If a mobile node transmitting data suddenly falls into a deeply faded environment, the link will be broken and re-transmission process initiated. This results in a very high overhead that degrades throughput performance for a highly dynamic wireless LAN e.g. in emergency-search-and-rescue application. A potential solution we propose is the use of diversity techniques, similar to those used in cellular systems. Diversity technique here however, will be employed at the MAC layer (at the routing protocol level) and not at the physical layer. If data can be routed from a source to a destination node via two or more paths, offering some diversity, throughput performance degradation due to fading will be improved.

3. Node Mobility:

A participating mobile node can move around at anytime and in any direction and at some instant of time may leave the coverage area of the entire network. If a node relaying data from a source to a destination node in a multi-hop wireless Ad hoc network leaves the network range mid-way in the data transfer process, the communication link breaks and the data will be retransmitted. In a highly dynamic network, where this can happen more frequently, throughput performance will degrade seriously. We propose the use of diversity technique in the data routing, as a solution to this problem too. When there are several diversity paths available from a source to a destination node, a link failure mid-way in a data transfer process, due to the exit of a relaying node from the network, will not stop the transfer process since the rest of the data transfer can be completed using the available alternate paths.

4. Interoperability:

Wireless LAN solution is based upon the expectations that participating nodes and associated devices such as access points, bridges, etc, will interoperate and intercommunicate when they are in range of one another. Unfortunately this may not be achieved where devices from various vendors are involved. Wireless LAN systems from different vendors might not be interoperable for the following reasons

Different technology will not interoperate. A system based on Frequency Hopping Spread Spectrum (FHSS) will not communicate with another based on Direct Sequence Spread Spectrum (DSSS). System using different frequency bands will not interoperate even if they both employ the same technology. Systems from different vendors may still not interoperate even if they both employ the same technology and the same frequency band, due to differences in implementation by each vendor.

While, Wi-Fi (802.11 compliant) products might overcome the problems of vendor compatibility and frequency band, multiple access differences remain a major problem for wireless LAN products interoperability since both FHSS and DSSS are supported in the 802.11 standards.

5. Security:

Because wireless technology has roots in military applications, security has long been a design criterion for wireless devices. To protect wireless LANs against any potential security issues, 802.11 specifications, section 8, laid down a security function called WEP (Wired Equivalent Privacy), which provides privacy compared to that of a traditional wired network. Though this level of protection against 'eavesdroppers' is adequate for basic users, more sophisticated users like military applications will need some special add-on security measures.

6. Power Management:

Managing the unit transmit power in wireless systems (both cellular and wireless network) has always been critical issues. In the cellular system however, built-in power conservation functions are incorporated to switch off the main circuitries when a unit is in idle mode. In a multi-hop wireless ad hoc network, this technique cannot easily be incorporated because nodes act as routers and idle nodes must still be powered to route data to other nodes when requested. This constitutes extra power utilizations for units in wireless network and thus makes power management a serious issue of consideration for successful deployments of wireless LANs.

V. Conclusions

This paper presents the implementation of wireless multi-hop Ad hoc networks based on IEEE 802.11b platform. Real-time experimental set ups were used to study the behaviors of such networks in typical real-time usage scenarios. Various issues found to be critical in the future deployments of such networks are enumerated and addressed.

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