Future Research Challenges for Ad Hoc Mobile Networks[1]

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Abstract - Ad hoc networks have attracted attention from the research community since the early nineties. The author himself was also deeply engrossed and interested in this area of research since that time. Earlier research was focused on ad hoc routing, i.e., on how routes can be discovered and how packets can be forwarded toward their destinations. Gradually over the years, other technical issues become important too, such as media access control protocols, ad hoc multicasting, and support for TCP over ad hoc networks. In this chapter, future research challenges for ad hoc mobile networks based on the author's own perspective are presented. In particular, the issues discussed are: (a) integrated ad hoc power management, (b) high capacity ad hoc networks, (c) integration of ad hoc and wireless LAN technologies, (d) quality of service support, (e) service discovery architectures, (f) forwarding models and incentives, and (g) address initialization, resolution and reuse.

Integrated Ad Hoc Power Management

While CPU speed is advancing with time, battery power life has still not reached quantum leaps. Most mobile devices today are powered using batteries and hence the operational lifetime of these devices is limited to a few hours before requiring recharge or battery replacement. If there is an electrochemical limit on battery capacity and lifetime, then smart power conservation is necessary.

Ad hoc networking is enabled through a set of communication protocols. These protocols are designed to support ad hoc routing, media access, multicasting and data transport. However, power issues may not necessarily be included in the design of these protocols. Traditionally, network protocols are designed to support communications, not power conservation. However, with the widespread use of mobile devices, its is crucial to optimize power usage to prolong the operation lifetime of these devices.

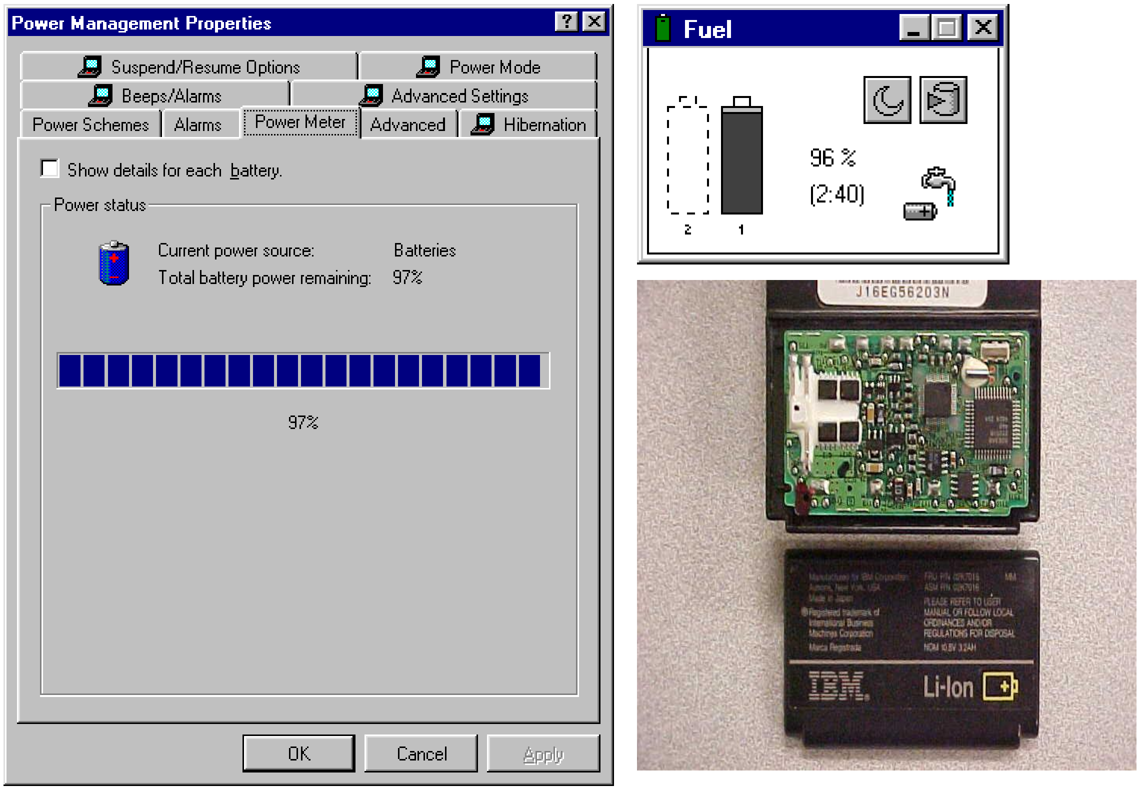
The overall power consumption of a device can be categorized into two major parts, namely: (a) communication-related, and (b) non-communications-related. Power consumed by device display, keyboard, disks, memory and CPU can be classified as non-communications related. Innovations had already been made to improve on ***"device" power consumption***, especially for the former. Protocol designers are beginning to look into embedding power-efficient features into communication protocols.

A major disjoint effort can be found in power-efficient protocol work. For example, proposals for power-efficient MAC protocol and power-efficient routing have been made. However, these

[1] This chapter was written by invitation from the editor. Readers who intend to use the information contained in this chapter for research proposals, lecturers, etc., should cite reference to this publication and warrant credits to the author.

protocols do not exhibit synergy in their power conservation operations, i.e., they operate in a mutually exclusive manner. For example, while the routing protocol might be choosing a route comprising minimum number of nodes with sufficient remaining power, the MAC protocol might be aggressively initiating packet retransmission in response to the poor fading channel. Hence, power conserved by the routing protocol may be ruined by the underlying MAC protocol.

In the author's perspective, power management has to occur at the ***device, protocol, and application layers***. Device power management is widely used in mobile computers today. More and more power-manageable hardware are designed and deployed. Advance power management (APM) tools are present to control power usage of a system based on the system's activity. Figures 1a and 1b show power management interface available on Microsoft Windows while Figure 1c reveals the presence of smart battery logic in battery packs for laptop computers. Several power states are introduced so that the system can be placed in specific power saving modes as the system is left idle or unused.


Power Management Properties

☐ Show details for each battery.

Power status

Current power source: Batteries
Total battery power remaining: 97%

97%

Fuel

96 %
(2:40)

Figure: 1(a) Power Monitor on Windows OS. (b) Fuel Indicator. (c) Smart Battery Logic in Battery Pack.

Power conservation at the protocol levels occurs at the *data-link* [1], *network*, and *transport* layers. At the data link layer, unnecessary retransmissions and collisions during channel access are avoided whenever possible. At the routing layer, routes are selected based on remaining battery life of nodes [4] and their route relaying loads [5]. Finally, at the transport layer, packet losses are handled in a localized manner whenever possible to conserve power. Avoiding repeated retransmissions during flow control can also conserve power. All these efforts, however, appear rather disjoint. Researchers have been working on power-efficient protocols at these layers independently. Power conserved at one layer does not necessary get conveyed down to the lower layers and vice versa. Hence, to achieve overall effectiveness in protocol power conservation, one has to strive for an **integrated power management framework**.

MAC protocol for Ad Hoc Networks

At the MAC layer, dedicated slots and channels can be co-ordinated among nodes in a route to ensure QoS requirements on channel access are met. Since nodes can be mobile, it is crucial that nodes selected for the communication path have to be “associatively” stable [5]. The absence of a centralized and fixed base station implies that channel access would not be entirely contention free.

In an environment where nodes share transmissions over a common channel, nodes supporting active routes should transmit more aggressively and neighboring nodes should back off and re-attempt at a less frequent interval. This provides some form of QoS assurance so that nodes in the route can transmit and forward packets within some bounded delay and bandwidth requirements.

The presence of asymmetric links [7] can make communications complicated. In mobile ad hoc networks, omni-directional radios give rise to hidden terminals and exposed nodes problems [9]. Directional antennas can alleviate some of these problems since signals can be directed in a specific spatial orientation. This feature also reduces the number of potential collisions in the channel. In sectorized systems, each sector is treated as a different cell. Hence, this allows further frequency reuse than possible in cellular systems.

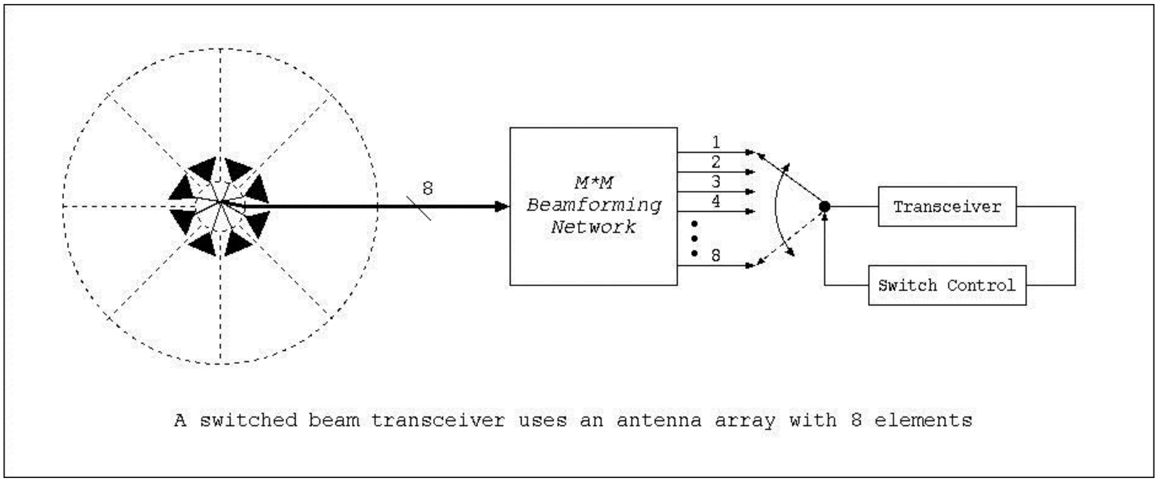

8
M*M
Beamforming
Network
1
2
3
4
8
Transceiver
Switch Control
A switched beam transceiver uses an antenna array with 8 elements

Figure 2: Switched beam smart antenna system.

Ad hoc networks may not be able to attain very high communication performance through the use of omni-directional radios. Smart antenna technologies have advanced to a stage where transmissions and receptions can be controlled electronically and spatially. Smart antennas are also very resilient toward multi-path fading. Currently, there are two forms of smart antenna systems: (a) switched beam, and (b) adaptive array. Switched beam antennas can be particularly useful when nodes are mobile. The structure of a switched beam antenna transceiver (SBAS) is shown in Figure 2. A SBAS system allows one to selectively transmit and receive at/from a specific antenna sector/array element. This feature allows one to reduce the probability of packet collision and signal interference.

Unlike switched beam antennas, adaptive array antennas has the ability to effectively locate and track various types of signals to dynamically minimize interference and maximize signal reception. This is achieved through the use of advanced signal processing techniques. By exploiting these features obtainable from smart antenna systems, the MAC protocol can further enhance link performance.

The challenge facing the design of smart-antenna based MAC protocol for ad hoc mobile networks is the ability to intelligently select appropriate sectors for transmissions and reception in order to counteract mobility, channel fading, asymmetric links, hidden terminals and exposed nodes problems. Some recent work utilized GPS information to aid antenna beam steering. However, this requires each node to be equipped with a GPS receiver. Another area worthy of research is power control for packet transmission and reception. With appropriate control, hidden terminal, exposed nodes, and packet collisions can be reduced.

Quality of Service Support for Ad Hoc

Supporting QoS in mobile networks presents great challenges. While roaming is an attractive feature to have for many mobile users, it is insufficient if their calls or connections are constantly dropped and restarted. In cellular networks, the core network is generally a wired network of switches and routers. The cellular base stations perform call admissions and co-ordinate channel access. Ad hoc networks, however, do not have a wired backbone. To support end-to-end QoS, all nodes in the route has to support the same notion and assurance of desired QoS.

QoS mapping is paramount toward achieving QoS assurance. QoS assurance is different from QoS guarantee. QoS has to be supported at MAC, routing, and transport layers. Most ad hoc routing protocols do not support QoS. Routing metric used merely refer to shortest path or minimum hop. However, bandwidth, delay, and packet loss (reliability or data delivery ratio) are important QoS parameters. Hence, built into current ad hoc routing protocols should be mechanisms to allow for ***route selection*** based on QoS requirements and QoS availability of the network over the selected route. Having the capability to select the best route that fulfils QoS requirements is desirable.

In addition to establishing QoS routes in response to route requests**, *QoS assurance during route reconfiguration*** has to be supported too. Past research was focused on finding alternate partial routes quickly and in a localized fashion. However, QoS considerations need to be made to ensure that end-to-end QoS requirements continue to be supported. Better still, the same mechanism to derive QoS routes during route requests can be reused to support route repair operations. This ensures uniformity and consistency.

There is also a need to distinguish flows using the same route. In ad hoc wireless communications, ***multi-flow*** and ***multi-route*** architectures exist. Multi-flows could co-exist over the same route. When this happened, a flow identifier is necessary. When multi-flows occur over different routes from the source to the destination, then they are less interdependent. The former is commonly referred to as ***mobile trunking***. This is analogous to the scenario of having multiple virtual channels on a virtual path as in ATM (Asynchronous Transfer Mode) technology. Mobility over a mobile trunking path could, therefore, affects multiple data traffic flows concurrently. For the latter case, however, route rerouting could be initiated and handled individually and independently.

Ad Hoc Service Discovery Architectures

Ad hoc mobile networks are self-organizing and adaptive networks. Devices of different forms and capabilities networked together and hence, certain devices could act as clients while others act as servers. This scenario resembles the client-server architecture found in distributed systems. However, what differs greatly is the presence of mobility, power, and bandwidth constraints in ad hoc mobile systems.

In the past, research work was focused on resource recovery in the Internet. With the vast information available in hosts scattered geographically across the Internet, intelligent mechanisms are needed for users to quickly and accurately locate and retrieve information from the network. The network is, therefore, viewed as the fast, rich, and distributed interconnection of information databases. Protocols proposed for such purpose include SLP (Service Location Protocol), SUN Jini, Salutation Protocol, and Simple Service Discovery Protocol (SSDP) [9]. However, none of these protocols are designed for error- and delay-prone wireless networks.

The inclusion of wireless connectivity in nodes and routers results in wireless networks. Bluetooth [10] is one such network that differs from cellular networks since there are no requirements for fixed radio base stations or access points. Although Bluetooth has its own service location protocol, it is still only applicable to single-hop piconets or scatternet based on a master-slave architecture. The dynamic nature of ad hoc mobile nodes could render the use of centralized service directory agents inappropriate (since it would result in poor performance).

In some service location architectures, *user*, *directory*, and *service* agents are used. The user agent (UA) is a software entity that searches for requested services on behalf of the client. Directory agents (DA) are used to act as a broker between the service provider (the server) and the service requester (the client). Service requests are intercepted by the DA, processed, and the outcome sent back to the requestor. Service providers, therefore, register their services to the nearest directory agent/s. These registrations have to be performed at a sufficient frequency so that the service records in the DAs are kept up-to-date.

The performance of a service location protocol can be measure by:

(a) ***Service availability*** **-** it defines what percentage of service requests sent by clients are fulfilled by the presence of service providers in the network.

(b) ***Control overhead*** **-** this concerns how much control overhead is incurred by the protocol.

(c) ***Speed of service access*** **-** this refers to the time taken to access the desired service from the server.

(d) ***Speed of service query-reply*** **-** this refers to the delay incurred from the time the request is sent by the requester till a reply is received. Note that this reply could be sent by the SA or DA.

Research work on ad hoc service discovery has been scarce even until today. One such work [11] investigate centralized, distributed, and hybrid approaches towards service discovery. It was discovered that the hybrid approach is more suitable to ad hoc networks due to the higher overall service availability with a lower incurred overhead. Further research is needed to derive new service discovery, location, and access paradigms.

Forwarding Models and Incentives

An ad hoc network is a form of community network, i.e., it relies on the willingness of ad hoc mobile hosts to forward and relay packets towards the destination. However, forwarding other hosts' packets can result in:

a. Dissipation of available battery power
b. Consumption of memory and CPU cycles
c. Possibility of security attack
d. Consumption of user bandwidth over the air

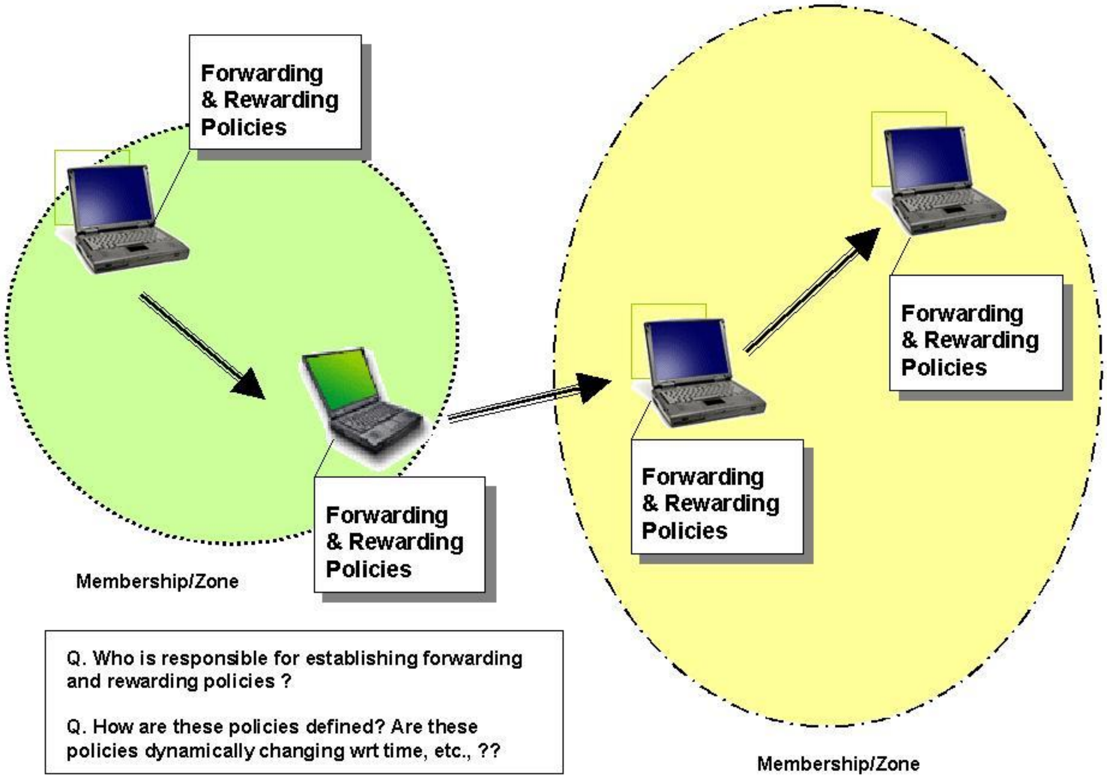

Forwarding & Rewarding Policies
Forwarding & Rewarding Policies
Forwarding & Rewarding Policies
Forwarding & Rewarding Policies
Membership/Zone
Q. Who is responsible for establishing forwarding and rewarding policies ?
Q. How are these policies defined? Are these policies dynamically changing wrt time, etc., ??
Membership/Zone

Figure 3: An illustration of forwarding and rewarding issues for ad hoc communications.

Figure 3 above implies that some forms of ***forwarding and rewarding models*** have to be established. Policies can be programmed into ad hoc mobile devices so that such devices will only forward packets that fulfil certain criteria, such as:

a. Originator and “group membership” of the host that transmit the packet
b. Any mutual "agreement" between the originator of the packet and the node that is pondering to relay the packet. Such agreement could include accumulation of credits (money wise, internet usage membership, security agreement, mutual forwarding contract, etc.,) for the node relaying the packets [12].
c. Packet zones - i.e., only packets originated from a certain network zone (or subnetwork) will be considered.

d. Urgency of the data to be relayed. This is familiar to domestic "911" calls where forwarding such data can save lives. Users may be much willing to forward such distress calls in a pervasive basis.

Clearly, many other factors can be taken into consideration to further refine forwarding and rewarding policies. An algorithm that takes all these factors into consideration and establishes these policies is needed. Who then should be responsible for establishing these policies in place? Should it be the telecommunications operators, service providers, or device manufacturers? Should such policies be established in a centralized or distributed manner? In the former scenario, users may submit their "desires and restrictions" to service providers. The service provider then registers concerned devices as "ad hoc mode enabled" and derives the forwarding and rewarding policies for them. Such policies can be programmed into the devices (via wireless links as in a mobile phone) or users might have to appear at certain establishments to have their devices configured. This, however, may be less favorable.

The distributed approach towards having the rewarding and forwarding policies established relies on devices communicating among each other and establishing the policies on their own. Users can specify and enter their desires into the device and can demand a new forwarding and rewarding policy be established. This would also mean that such policies could dynamically change over time with changing environment and availability of network resources and battery life. However, a generic algorithm has to exist in the device to allow this to happen. Further research is therefore necessary.

Ad Hoc Addressing & Naming

Ad hoc networks need some form of addressing so that hosts can be identified and packets can be relayed hop-by-hop and delivered ultimately to the destination. Ad hoc networks that do not need to be connected to the backbone Internet can be viewed as an isolated network. This implies that hosts in this network can practically take any unique addresses. However, even if the environment is a standalone ad hoc network, the following issues need to be considered:

a. **Address Syntax -** should addresses for ad hoc mobile hosts be classified into classes as in IP addressing and should it also contain the network and host portions? Will ad hoc networks contain subnetworks? How does one ensure uniqueness in addresses?

b. **Address Initialization -** Who should initialize each host with the appropriate network address? Recall that such assignments have to be unique to each host in the network.

c. **Address Conflicts -** When an ad hoc intra-network migrates to the proximity of another, there is potential possibility of address conflicts. Under such circumstances, conflicts have to be resolved in a swift manner.

d. **Address Resolution -** How would hosts in an ad hoc intranet know their destination nodes' address?

e. **Address Reuse -** Once a node belonging to one intra-network migrates away, there is great possibility to reuse the "lost" network address. Again, how can this migration be detected and address freed and reused?

f. **Unreachable Hosts -** How are unreachable hosts handled? Are ad hoc routers still capable of responding with ICMP messages?

Who should act as the address allocation agency? Is DHCP (Dynamic Host Configuration Protocol) even possible or applicable? In addition to addressing issues, naming presents another great challenge. In the past, users utilize names for ease of remembrance and identification. Names hide the specifics of numeric addresses from the users. The resolution of name to addresses is achieved through the use of name servers. Such servers are organized in a logical and hierarchical manner such that name-address queries are propagated to the upper level server if the local server is unable to resolve the query. Normally, the resolution can be achieved in a short time due to the high speed interconnection of servers.

For ad hoc mobile networks, would it be possible to support naming? How would a node be selected to act as the name server? What would happen when an assigned name server node migrates away? **Could names reflect a better syntax to define the host and the environment surrounding it (or so called "domain")?** How should we define the **resultant naming space** so that heterogeneous wired and mobile networks can be included? This could have serious implications for the tactical environment.

Connection Precedence & Preemption

Ad hoc mobile networks are envisaged to provide data, audio, and video services to mobile users. In the defense era, provision of multimedia services is considered important. In addition, mobile users differ by their ranks, type of decisions, and resulting actions. Hence, a high-ranking official might want his connection request to be fulfilled, in view of the importance and urgency of his actions. If the route path chosen has been preoccupied, it might be necessary to allow the new connection request to pre-empt the existing connection. While the provision of this feature is particularly attractive for battlefield scenarios, it does require changes to underlying protocols.

For on-demand source-initiated routing protocols, if a new request with a higher precedence level originates at a source node which already have multiple routes active, then a check procedure has to occur. If the request results in a route path that is already congested, then decision has to be made to select an existing route to preempt in order to grant this request. For protocols where route selection is performed at the destination, it is at this point that the destination node performs route preemption. All nodes in the preempted route have to be informed and their forwarding tables updated. The application at both source and destination nodes have to be terminated and the user informed. This can be termed as "end-point" preemption.

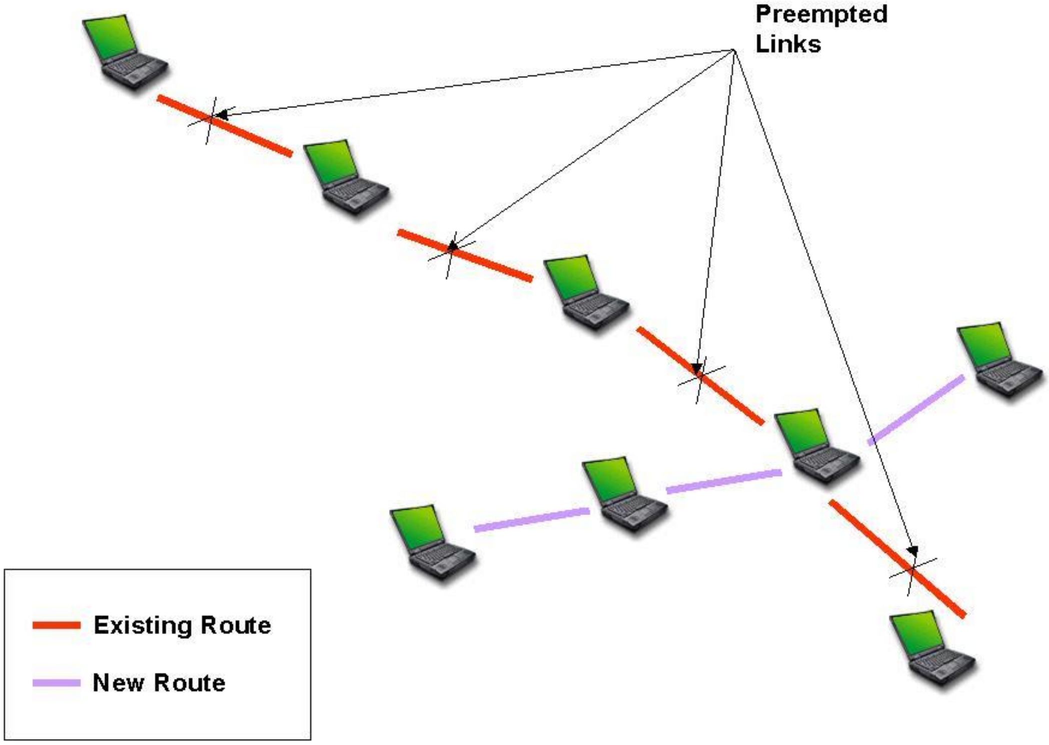


Figure 4: An existing route could be preempted by another upcoming route due to nature of urgency and importance.

A follow up of this event is the use of re-routing instead of having the connection dropped as a result of preemption. Re-routing will cause some form of disruptions to existing data flows but it is still less annoying than dropping a connection. A disadvantage of initiating rerouting is that it could defer the preemption process, i.e., resources tied down by the current route could not be released until an alternative route is found to complete the rerouting process. This could result in severe implications for the preempting user.

Route pre-emption could also be triggered by an intermediate node. Suppose an active route Q exists on SRC1, N1, N2, N3, and DEST1. Suppose another node SRC2 initiates a route request towards DEST2. Suppose the chosen route W is SRC2, N8, N7, N3, N5, DEST2. Hence, N3 is common to both routes. However, when N3 received the path setup message from DEST2, decision to preempt route Q is already contained within the setup packet. Hence, N3 could initiate route Q to be preempted by sending control packets to N3 upstream and downstream nodes on route Q.

Research is needed to investigate when, and how preemption of communication paths can be supported in ad hoc mobile networks. Intelligent control of preemption activities can result in offering communications to those when urgently in need (hence fulfilling critical applications and requests) while at the same time allowing effective use of the network for data transport to mobile users. A network with connections preempted most of the time could render the network unusable! This demands further study.

Conclusion

A new form of networking technology has evolved where dynamic network formation can occur over a multitude of heterogeneous devices. Research into the area of ad hoc mobile networking has begun since the early 1990s. Gradually, issues related to routing and multicasting have been addressed. In this chapter, the author highlights remaining technical challenges prior to the realization of a usable self-organizing and adaptive mobile network. While the infrastructure formation and data transport mechanism is essential, the provision of host/network addressing, security, QoS, and client/server services are crucial to mobile users. Discussions have been made on the use of ad hoc networking in intelligent transport highways, underground train station networks, pedestrian telecommunication networks, defense sensors networks, etc. By further investigating these remaining challenges, we will be one step closer toward realizing and deploying ad hoc mobile networks and services.

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