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THE PRAGMATIC INVESTIGATION OF AD-HOC NETWORKS AND RELATED ASPECTS

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ABSTRACT: In present Era, many people carry legion portable devices, such as laptops, mobile phones, PDAs and mp3 players, for use in their professional and private lives. For the most part, these devices are used separately that is, their applications do not interact. Imagine, however, if they could interact directly: participants at a meeting could share documents or presentations; business cards would automatically find their way into the address register on a laptop and the number register on a mobile phone; as commuters exit a train, their laptops could remain online; likewise, incoming email could now be disported to their PDAs; finally, as they enter the office, all communication could automatically be routed through the wireless corporate campus network. These examples of self-generated, ad hoc wireless communication between devices might be loosely defined as a scheme, often referred to as ad hoc networking, which allows

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devices to establish communication, anytime and anywhere without the aid of a central infrastructure. Actually, ad hoc networking as such is not new, but the setting, usage and players are. In the past, the notion of ad hoc networks was often associated with communication on combat fields and at the site of a disaster area; now, as novel technologies such as Bluetooth materialize, the scenario of ad-hoc networking is likely to change, as is its importance. In this article, the authors describe the concept of ad hoc networking by giving its background and presenting some of the technical challenges it poses. The authors also point out some of the applications that can be envisioned for ad hoc networking.

1. Introduction

An ad hoc network is a assemblage of wireless mobile hosts forming a temporary network without the aid of any established infrastructure or centralized administration. In such an environment, it may be necessary for one mobile host to enlist the aid of other hosts in forwarding a packet to its destination, due to the limited range of each mobile host's wireless transmissions. Mobile ad hoc networks (MANET) do not rely on any fixed infrastructure but communicate in a self-organized way. Numerous factors associated with technology, business, regulation and social behavior naturally and logically speak in favor of wireless ad hoc networking. Mobile wireless data communication, which is encouraging both in terms of technology and usage/ insight, is a driving force, thanks to the Internet and the success of

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second-generation cellular systems. As we look to the horizon, we can finally glance a view of truly omnipresent computing and communication.

In the near future, the role and capabilities of short-range data transaction are expected to grow, serving as a complement to traditional large-scale communication: most man machine communication as well as oral communication between human beings occurs at distances of less than 10 meters; also, as a result of this communication, the two communicating parties often have a need to exchange data. As an enabling factor, license- excused frequency bands invite the use of developing radio technologies (such as Bluetooth) that admit effortless and inexpensive deployment of wireless communication.

In terms of price, portability and usability and in the circumstance of an ad hoc network, many computing and communication devices, such as PDAs and mobile phones, already own the attributes that are worthy. As advances in technology continue, these attributes will be enhanced even further

2. Question: What is an ad hoc network?

Answer: An Ad hoc networking is a Self-organizing and adaptive technology. It allows spontaneous formation and deformation of mobile networks. Each mobile host acts as a router Supports peer-to-peer communications and also supports peer-to-remote Communications. It reduces administrative cost and provides ease of deployment.

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The roots of ad hoc networking can be followed back as far as 1968, when work on the ALOHA network was initiated (the objective of this network was to connect educational facilities in Hawaii). Although fixed stations were applied, the ALOHA protocol lent itself to distributed channel access management and hence provided a basis for the subsequent development of distributed channel-access schemes that were suitable for ad hoc networking. The ALOHA protocol itself was a single-hop protocol that is; it did not inherently support routing. Instead every node had to be within reach of all other participating nodes. Inspired by the ALOHA network and the early development of fixed network packet switching, DARPA began work, in 1973, on the PRnet (packet radio network) multichip network.2 In this context, multihopping means that nodes cooperated to relay traffic on behalf of one another to reach distant stations that would otherwise have been out of range. PR net provided mechanisms for managing operation centrally as well as on a distributed basis. As an additional profit, it was realized that multihopping techniques increased network capacity, since the spatial domain could be reused for concurrent but physically separate multichip sessions.

3. Ad Hoc Networks – Operating Principle

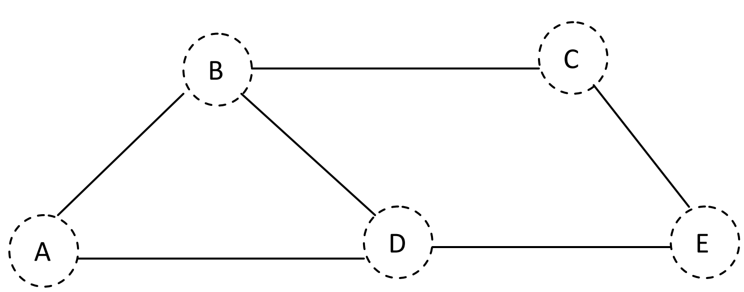

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Figure 1. Example of an Ad-hoc Network

Fig. depicts a peer-to-peer multihop ad hoc network

❒ Mobile node A communicates directly with B (single hop) when a channel is available.

❒ If Channel is not available, and then multi-hop communication is necessary e.g. A->D->B.

❒ for multi-hop communication to work, the intermediate nodes should route the packet i.e. they should act as a router.

❒ Example: For communication between A-C, B, or D & E, should act as routers.

4. Bringing up an Ad hoc Network

1. Ad hoc network begins with at least two nodes broadcasting their presence with their respective address information.

2. They may also include their location info if GPS equipped.

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3. Beaconing messages are control messages. If node A is able to establish a direct communication with node B verified by appropriate control messages between them, they both update their routing tables.

4. Third node C joins the network with its beacon signal. Two scenarios are possible:

(i) A & B both try to determine if single hop communication is feasible.

(ii) Only one of the nodes e.g. B tries to determine if single hop communication is feasible and establishes a connection.

5. The distinct topology updates consisting of both address and the route updates are made in three nodes immediately.

6. In first scenario, all routes are direct i.e. A->B,B->C, and A->C (Let's assume bi-directional links).

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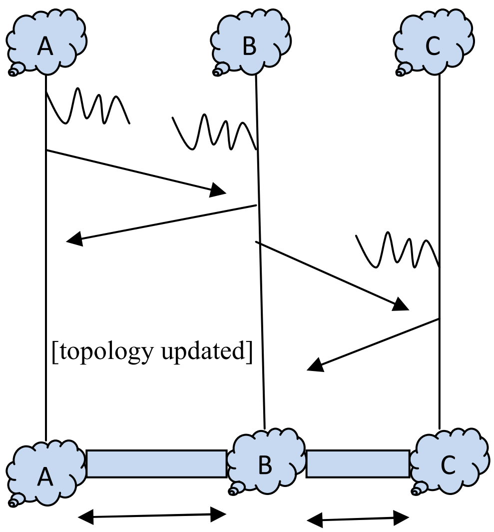

Figure 2

5. Typical applications

Mobile ad hoc networks have been the focus of many recent research and development efforts. So far, ad hoc packet-radio networks have mainly been conceived for military applications, where a decentralized network configuration is an operative advantage or even a necessity. Wireless, mobile computing has not been available at a price attractive to large markets. However, as the capacity of mobile computers increases steadily, the need for unlimited networking is also asked to rise. Commercial ad hoc networks could be used in situations where no infrastructure (fixed or cellular) is available. Examples include rescue operations in remote areas, or when local coverage must be deployed quickly at a remote construction site. Ad hoc

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networking could also serve as wireless public access in urban areas, providing quick deployment and extended coverage. The access points in networks of this kind could serve as stationary radio relay stations that perform ad hoc routing among themselves and between user nodes. Some of the access points would also provide gateways via which users might connect to a fixed backbone network. At the local level, ad hoc networks that link notebook or palmtop computers could be used to spread and share information among participants at a conference. They might also be appropriate for application in home networks where devices can communicate directly to exchange information, such as audio/video, alarms, and configuration updates. Perhaps the most far-reaching applications in this context are more or less autonomous networks of interconnected home robots that clean, do dishes, mow the lawn, perform security surveillance, and so on. Some people have even proposed ad hoc multichip networks (denoted sensor networks) for example, for environmental monitoring, where the networks could be used to forecast water pollution or to provide early warning of an approaching tsunami.

6. Challenges in Ad hoc Mobile Networks

1. Host is no longer an end system - can also be an acting intermediate system Changing the network topology over time.

2. Potentially frequent network partitions.

3. Every node can be mobile.

4. Limited power capacity.

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5. Limited wireless bandwidth.

6. Presence of varying channel quality.

7. PAN-a network extension

Seen from the viewpoint of the traditional mobile network, a Bluetooth-based PAN opens up a new way of extending mobile networks into the user domain. Someone on a trip who has access to a Bluetooth PAN could use the GPRS/UMTS mobile phone as a gateway to the Internet or to a corporate IP network. In terms of traffic load in the network, the aggregate traffic of the PAN would typically exceed that of the mobile phone. In addition, if Bluetooth PANs could be interconnected with scatter nets, this capacity would be increased.

A PAN can also comprehend several different access technologies dispersed among its member devices which exploit the ad hoc functionality in the PAN. For instance, a notebook computer could have a wireless LAN (WLAN) interface that provides network access when the computer is used indoors. Thus, the PAN would benefit from the total aggregate of all access technologies residing in the PAN devices. As the PAN concept matures, it will allow new devices and new access technologies to be incorporated into the PAN framework. It should also eliminate the need to create hybrid devices, such as a PDA-mobile phone combination, because the PAN network will instead allow for wireless integration. In other words, it will not be necessary to trade off form for function. In all the scenarios discussed above, it should be emphasized that

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close-range radio technology, such as Bluetooth, is a key enabler for introducing the flexibility represented by the PAN concept.

8. Characteristics and requirements

Unlike wire line or wireless networks, an ad hoc network could be anticipated to operate in a network environment in which some or all the nodes are mobile. In this dynamic environment, the network functions must run in a distributed fashion, since nodes might suddenly vanish from, or show up in, the network. In general, however, the same basic user requirements for connectivity and traffic delivery that apply to traditional networks will apply to ad hoc networks. Below, we discuss some typical operational characteristics and how they affect the requirements for related networking functions. To limit the scope of the discussion, we will analyze the case of a PAN oriented ad hoc network that involves a mix of notebook computers, cellular phones, and PDAs. Distributed operation: a node in an ad hoc network cannot rely on a network in the background to support security and routing functions. Instead these functions must be designed so that they can operate efficiently under distributed conditions. Dynamic network topology: in general, the nodes will be mobile, which sooner or later will result in a varying network topology. Nonetheless, connectivity in the network should be maintained to allow applications and services to operate undisrupted. In particular, this will influence the design of routing protocols. Moreover, a user in the ad hoc network will also require access to a fixed network (such as the Internet) even if nodes are moving around. This calls for mobility management functions that allow network access for devices located several radio hops away from a network

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access point. Fluctuating link capacity: the effects of high bit-error rates might be more profound in a multichip ad hoc network, since the aggregate of all link errors is what affects a multichip path. In addition, more than one end-to-end path can use a given link, which if the link were to break, could disrupt several sessions during periods of high bit-error transmission rates. Here, too, the routing function is affected, but efficient functions for link layer protection (such as forward error correction, FEC, and automatic repeat request, ARQ) can substantially improve the link quality. Low-power devices: in many cases, the network nodes will be battery-driven, which will make the power budget tight for all the power-consuming components in a device. This will affect, for instance,

CPU processing, memory size/usage, signal processing, and transceiver output/input power. The communication-related functions (basically the entire protocol stack below the applications) directly burden the application and services running in the device. Thus, the algorithms and mechanisms that implement the networking functions should be optimized for lean power consumption, so as to save capacity for the applications while still providing good communication performance. Besides achieving reasonable network connectivity, the introduction of multiple radio hops might also improve overall performance, given a constrained power budget. Today, however, this can only be realized at the price of more complex routing. Given the operating conditions listed above, what can the user expect from an ad hoc PAN network? The support of multimedia services will most likely be required within and throughout the ad hoc PAN. As an example, the following four quality-of-service (QoS) classes would facilitate the use of multimedia applications including

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1. Conversational (voice);

2. Streaming (video/audio);

3. Interactive (Web); and

4. Background (FTP, etc.).

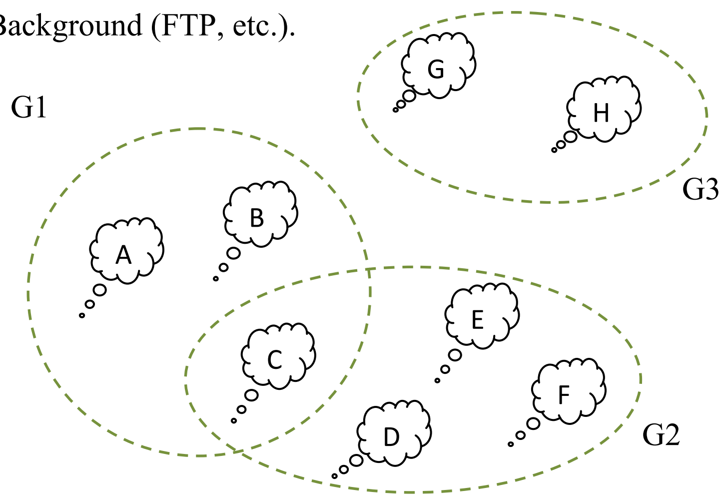

Figure 3. This ad hoc network has three separate trust groups: G1, G2 and G3. At this stage, a secure exchange of data cannot occur between the nodes except with node C, which belongs to G1 and G2. These service classes have been named for QoS support in the UMTS network and should also be endorsed in the PAN environment. However, the underlying stochastic communications quality in a wireless ad hoc network, as discussed above, makes it difficult to offer fixed guarantees on the services offered to a device. In networks of this kind, fixed guarantees would result in requirements for how nodes move, as well as requirements for node density, which would inherently inhibit the notion of ad hoc operation. However, when

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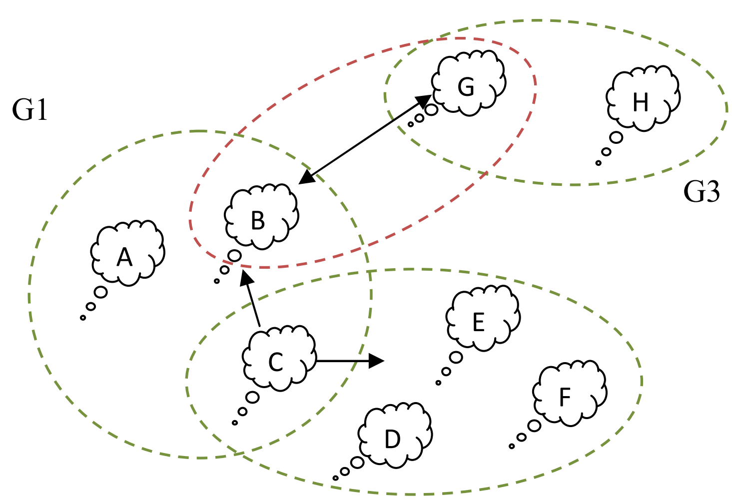
communication conditions are stable, the PAN substructure should provide the same QoS as has been defined for the access network. To further improve user perception of the service, user applications that run over an ad hoc network could be made to adapt to sudden changes in transmission quality.QoS support in an ad hoc network will affect most of the networking functions discussed above, especially routing and mobility. In addition, local buffer management and priority mechanisms must be deployed in the devices in order to handle differentiated traffic streams. In the following section we elaborate more on three of the functions briefly mentioned above, namely, security, routing, and mobility. We believe that these functions are good points of departure for a discussion of the implications that ad hoc operation will have on network functionality.



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G2

Figure 4.Node C sends the signed public keys it received from nodes D, E and F to server node A. In addition, node A establishes a new trust relationship to node G.

9. Typical ad hoc network functions

9.1. Security

Evidently, security is a pertain in an ad hoc network, in particular if multiple hops are employed. How can a user be certain that no one is listening in on traffic via a for- warding node? Is the user at the other end really the person he claims to be? From a purely cryptographic point of view, ad hoc services do not imply many new problems.

The requirements considering authentication, confidentiality, and integrity or non repudiation are the same as for many other public communication networks. However, in a wireless ad hoc network, trust is a central problem. Since we cannot trust the medium, our only choice is to use cryptography, which forces us to rely on the cryptographic keys used. Thus, the basic challenge is to create trusted relationships between keys without the aid of a trusted third-party certification.

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Since ad hoc networks are created spontaneously between entities that happen to be at the same physical location, there is no guarantee that every node holds the trusted public keys to other nodes or that they can present certificates that will be trusted by other parties. However, if we allow trust to be delegated between nodes, nodes that already have established trusted relationships can extend this privilege to other members of the group.

The method described below can be used for distributing relationships of trust to an entire ad hoc network. The method is based on a public key approach and is exemplified by a small ad hoc network (Figures 3-6). We assume that connectivity exists between all the nodes in the network, and that it can be maintained by, say, a reactive ad hoc routing protocol.

1. Initially, node A takes on the role of server node in the procedure of delegating trust. A triggers the procedure by flooding a start message into the network. Each node that receives this message floods the ad hoc network with a message containing the set of trusted public keys. A can then establish a map of trusted relations and identify them in the ad hoc network. In the example shown (Figure 3), three different groups (G1, G2, and G3) share a chain of trust.

2. All the nodes in G2 share an indirect trusted relationship to a (through node C). Node A can thus collect the signed keys it received from G2 via C (as illustrated in Figure 3). By contrast, the nodes in G3 do not have a trusted relationship to A. However, a trusted relationship between, say, node G in G3 and A can be created by manually exchanging trusted keys.

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3. Node A can now collect signed keys received from G3 via G (Figure 5). A can then flood the ad hoc network with all collected signed keys. This procedure creates trusted relationships between every node in G1, G2 and G3, and forms a new trust group, G1Õ (Figure 6).This example can be generalized into a protocol that handles the distribution of trust in an arbitrary ad hoc network.

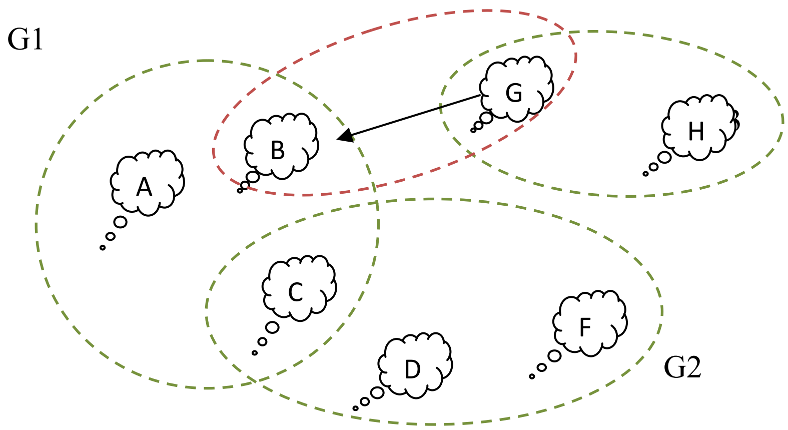

Figure 5. Node G sends the signed public key it received from node H to node A.

9.2. Routing in ad hoc networks

For mobile ad hoc networks, the issue of routing packets between any pair of nodes becomes a challenging task because the nodes can move randomly within the network. A path that was considered optimal at a given point in time might not work at all a few moments later. Moreover, the stochastic properties of the wireless channels add to the uncertainty of path

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quality. The operating environment as such might also cause problems for indoor scenarios the closing of a door might cause a path to be disrupted. Traditional routing protocols are proactive in that they maintain routes to all nodes, including nodes to which no packets are being sent. They react to any change in the topology even if no traffic is affected by the change, and they require periodic control messages to maintain routes to every node in the network. The rate at which these control messages are sent must reflect the dynamics of the network in order to maintain valid routes. Thus, scarce resources such as power and link bandwidth will be used more frequently for control traffic as node mobility increases.

An alternative approach involves establishing reactive routes, which prescribes that routes between nodes are determined solely when they are explicitly needed to route packets. This prevents the nodes from updating every possible route in the network, and instead allows them to focus either on routes that are being used, or on routes that are in the process of being set up.

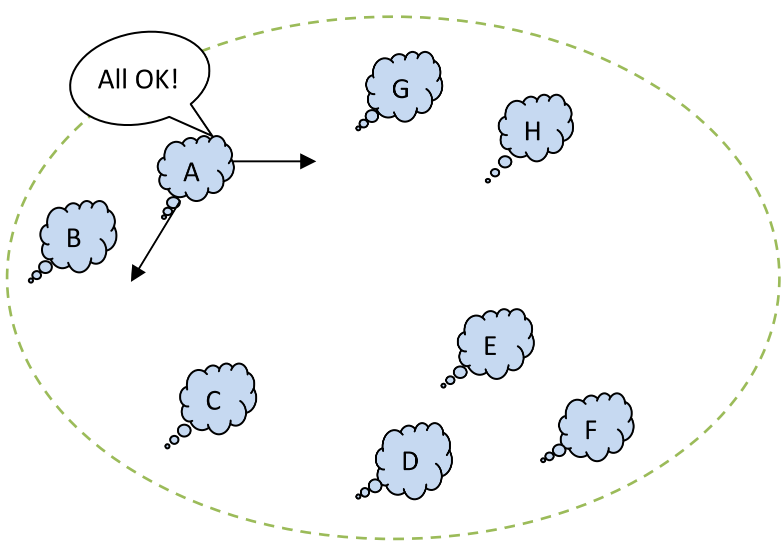

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Figure 6. Node A floods the ad hoc network with all the signed keys. A new chain of trust is thus created in a new, secure trust group, G1', which comprises all the nodes in the network.

9.3. THREE MOBILE AD HOC NETWORK-ROUTING PROTOCOLS

9.3.1. Destination-sequenced distance vector

DSDV is a proactive hop-by-hop distance vector routing protocol. Each network node maintains a routing table that contains the next hop to any approachable destination as well as the number of hops that will be required. Periodical broadcasts of routing updates are used to keep the routing table completely updated at all times. To guarantee loop-freedom, DSDV uses a concept that is based on sequence numbers to indicate how new, or fresh, a given route is. Route R, for example, will be considered more favorable than R' if R has a higher sequence number; whereas if the routes have the same sequence number, R will have the lower, or more recent, hop-count.

Note: in a distance vector (or Bellman-Ford) algorithm, the network nodes exchange routing information with their neighbors. The routing table in a node contains the next hop for every destination in the network, and is associated with a distance metric for example, the number of hops. Based on the distance information in the neighbors routing tables, it is possible to compute

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the shortest-path (or minimum-cost) routes to every destination in a finite time for a network with no topology changes.

9.3.2. Ad hoc on-demand distance vector

Like DSDV, AODV is a distance vector routing protocol, but it is reactive. This means that AODV solely requests a route when it needs one, and does not require that the nodes should maintain routes to destinations that are not communicating. AODV uses sequence numbers in a way similar to DSDV to avoid routing loops and to indicate the freshness of a route. Whenever a node needs to find a route to another node, it broadcasts a route request (RREQ) message to all its neighbors. The RREQ message is deluged through the network until it reaches the destination or a node that has a fresh route to the destination. On its way through the network, the RREQ message initiates the creation of temporary route table entries for the reverse route in the nodes it passes. If the destination or a route to it is found, its availability will be indicated by a route reply (RREP) message that is uncast back to the source along the temporary reverse path of the received RREQ message. On its way back to the source, the RREP message initiates, in the intermediate nodes, routing table entries for the destination. Routing table entries expire after a certain timeout period.

9.3.3. Dynamic source routing

Dynamic source routing is a reactive routing protocol that uses source routing to deliver data packets. The headers of the data packets carry the addresses of the nodes through which the

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packet must pass. This means that intermediate nodes need only keep track of their immediate neighbors in order to forward data packets. The source, on the other hand, must know the complete hop sequence to the destination.

As in AODV, the route acquisition procedure in DSR requests a route by flooding the system with an RREQ packet. A node that receives an RREQ packet searches its route cache, where all its known routes are stored, for a route to the requested destination. If no route is found, it forwards the RREQ packet after first having added its own address to the hop sequence stored in the packet. The packet propagates through the network until it reaches either the destination, or a node with a route to the destination. If a route is found, an RREP packet containing the proper hop sequence for reaching the destination is uncast back to the source node. Another feature of the DSR protocol is that it can learn routes from the source routes in packets it receives.

10. Mobility functions

In present-day cellular networks, node and user mobility are handled mainly by means of forwarding. Thus, when a user circulates outside his home network any calls directed to him will be forwarded to the visiting network via his home network. This same forwarding principle applies to mobile IP[12, 13]. A user, or actually the node with the IP interface, can also continue to use an IP address outside the sub network to which it belongs. A roaming node that enters a foreign network is associated with ac/o address provided by a foreign agent (FA). In the home network, a home agent (HA) establishes an IP tunnel to the FA using the c/o address. Any packet sent to the roaming nodes address is first sent to the home agent, which forwards it to the FA via

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the c/o address (Tunneling). The FA then encapsulates the packet and sends it to the roaming node using the original (home) IP address. The actual routing in the fixed network is not affected by this tunneling method and can use traditional routing protocols such as open shortest path first (OSPF), the routing information protocol (RIP), and the border gateway protocol (BGP). This forwarding approach is appropriate in cases where only the nodes (terminals) at the very edges of (fixed) networks are moving. However, in an ad hoc network, this is not the case, since the nodes at the center of the network can also move or rather, the whole network is based on the idea of devices that serve both as routers and hosts at the same time. Hence, in an ad hoc network, mobility is handled directly by the routing algorithm. If a node moves, forcing traffic another way, the routing protocol takes care of the changes in the nodes routing table. In many cases, interworking can be expected between ad hoc and fixed networks. Interworking would make it possible for a user on a trip who takes part in a laptop conference but wants mobility, to be reachable via the fixed IP network. Moreover, since the user wants to be reachable from the fixed network, mobile IP would be a convenient way of making him reachable through the fixed IP network. If the user is located several radio hops away from the access point, mobile IP and the ad hoc network routing protocol must interwork to provide connectivity between the travelling user and his unit's peer node, which is located in the fixed network or in another ad hoc network.

11. Bluetooth networking

Worldwide, the industry has shown a enormous interest in techniques that provide short-range wireless connectivity. In this context, Bluetooth technology is seen as the key component.

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Nevertheless, Bluetooth technology must be able to operate in ad hoc networks that can be stand-alone, or part of the "IP-networked" world, or a combination of the two.

The main purpose of Bluetooth is to replace cables between electronic devices, such as telephones, PDAs, laptop computers, digital cameras, printers, and fax machines, by using a low-cost radio chip. Short-range connectivity also fits nicely into the wide area context, in that it can extend IP networking into the personal-area network domain.

Bluetooth must be able to carry IP efficiently in a PAN, since PANs will be connected to the Internet via UMTS or corporate LANs, and will contain IP-enabled hosts. Usually speaking, a good capacity for carrying IP would give Bluetooth networks a wider and more open interface, which would most certainly boost the development of new applications for Bluetooth.

11.1. Bluetooth basics

Bluetooth is a wireless communication technology that uses a frequency-hopping scheme in the unlicensed Industrial- Scientific-Medical (ISM) band at 2.4 GHz. Two or more Bluetooth units that share the same channel form a piconet (Figure 10).

Within a piconet, a Bluetooth unit can play either of two roles: master or slave. Each piconet may only contain one master (and there must always be one) and up to seven active slaves. Any Bluetooth unit can become a master in a piconet.

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Furthermore, two or more piconets can be interconnected, forming what is called a scatter net. The connection point between two piconets consists of a Bluetooth unit that is a member of both piconets. A Bluetooth unit can simultaneously be a slave member of multiple piconets, but only a master in one. Moreover, because a Bluetooth unit can only transmit and receive data in one piconet at a time, its participation in multiple piconets has to be on a time division multiplex basis. The Bluetooth system provides duplex transmission based on slotted time-division duplex (TDD), where the duration of each slot is 0.625 ms. There is no direct transmission between slaves in a Bluetooth piconet, only from master to slave and vice versa. Communication in a piconet is organized so that the master polls each slave according to a polling scheme. A slave is only allowed to transmit after having been polled by the master. The slave will start its transmission in the slave-to-master timeslot immediately after it has received a packet from the master. The master may or may not include data in the packet used to poll a slave. However, it is possible to send packets that cover multiple slots. These multi slot packets may be either three or five slots long.

11.2. Scatter net-based PANs

Bluetooth networks will most likely be used to interconnect devices such as cellular phones, PDAs, and notebook computers in other words, via a PAN. The PAN itself can be a Bluetooth-based IP network in all likelihood it will be based on a single piconet topology. However, when a PAN user wants to connect to one or more other PANs, Bluetooth scatternet capability will serve as the foundation for the IP network. Similarly, if one or more PANs connect to an Internet access point on a LAN (LAN access point, LAP) a scatternet will provide the underlying Bluetooth infrastructure. We can expect to see a combination of PAN interconnection and Internet access. In addition, Internet access to one PAN or several interconnected PANs can be provided by using a cellular phone (for example, via GPRS/UMTS) as a bridge/router gateway.

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