RESEARCH ON AD HOC NETWORKING: CURRENT ACTIVITY AND FUTURE DIRECTIONS

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Abstract

This article is a survey on the current status and direction of research on ad hoc networking. We categorize the ongoing research and outline the major challenges which have to be solved before widespread deployment of the technology is possible. The views presented by Perkins in [1] are used as a premise, which is then complemented with discussion and references to the latest publications.

1 Introduction

Ad hoc networks (AHNs) are wireless multi-hop packet networks without any fixed infrastructure. An AHN network is formed solely by its terminals so that each terminal connected to the network provides also relaying service for others, i.e. acts as a router. Advantages of such system are rapid deployment, robustness, flexibility and inherent support for mobility.

AHN can work as a stand-alone autonomous network providing internal connections for a group. Demand for such networks could arise in the contexts of shared desktop meeting, disaster recovery, or in various military applications. However, no commercial "killer applications" are known for this technology yet.

In the future, ad hoc networks probably form the outermost region of the internetwork, where a wired backbone connects both the fixed local area networks and the mobile (both the fixed infrastructure and the ad hoc) networks. Whereas the base stations of a fixed infrastructure networks are directly connected to the core, an AHN is typically connected through a satellite link or a terrestrial switch (fixed wired connection point, or mobile radio link). This vision, however, requires still some further developments in ad hoc networking.

Basic research and potential applications of ad hoc networks are evolving together, spurring each other into further achievements. The need for an application can give directions for the research and, on the other hand, the research enables new applications to be created. Although this network concept has been originally considered in the context of packet radio networks [2] earlier, it has become very popular again during the past few years. The work is going on within the IETF's MANET working group [3] for standards and the research is very active throughout the world.

Currently the most fundamental research issue in ad hoc networking, between the physical layer and the application layer, is packet routing. In fixed infrastructure mobile networks routing is, for the most part, an engineering problem (implementation of hand-overs etc.), whereas in ad hoc networks it is essentially theoretical. The problems and their solutions considering packet routing are closely related to those widely studied in the case of ordinary fixed networks, but also completely new fundamental challenges have emerged due to the peculiar features of AHNs, such as:

- Dynamic network topology and structure
  - Nodes may join or leave the network
  - Some or all nodes may be mobile
- Limited bandwidth
- Constrained power
- Broadcast nature of transmission

In this paper, we discuss the on-going research efforts to tackle the problems between the present day and the vision of practical ad hoc networking solutions. We survey the current work in progress in the field and also anticipate some of the next steps the research is taking. The leading theme is the intellectual challenge posed by this new technology. Therefore, we select the important issues which are to be solved in order to enable widespread ad hoc network deployment and concentrate on very general level instead of protocol specific details. In other words, algorithms and ideas are preferred to implementations. Emphasis is on the topics that are not discussed otherwise in this seminar.

The "new world" of AHN technology has been visited by now, there is no such thing that completely unexplored territories in this field. Active research has produced a wide range of proposals, but so far not many problems are solved. We start from the issues recognized in [1], with a few additions, and describe their recent development with the latest pointers to selected literature. Subjectivity cannot be avoided in this sort of study, so the reader is pleaded to be gentle in his or her criticism.

The area is developing at the pace of several hundreds of publications yearly and the speed unavoidably outdates any summaries, conclusions and predictions in very short time. It is clear that ad hoc networking is in its infancy what comes to its research and further development are being expected for years to come. Hence, previous works considering the future research in this field have been very few in number. In addition to [1] these issues are treated in [4], and in [5] the wireless networks research was considered in general. From the application point of view, another notable instance relevant the topic is the Wireless World Research Forum (WWRF) [6], a forum founded by several leading telecom corporations. Their Book of Vision attempts to recognize future research strategies in all wireless communications.

The organization of the rest of this paper is as follows. In Section 2 we analyze publishing activity in 2001 to get a picture on the key topics. Section 3 goes down to the details of open research issues, starting from the ideas in [1] and discussing the current development in each of the areas as well as the questions that are still lacking any kind of resolution. In Section 4 we briefly go through two large scale projects that are going on as examples of comprehensive studies to bring AHNs into existence before concluding with some futuristic visions in Section 5.

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Table 1: Publications on ad hoc networks within IEEE during 2001, see Figure 1 for illustration

2 Research status

This section attempts to summarize the current research that is being conducted on ad hoc networks. Due to the vast amount of the material about the topic, we chose to take a representative sample of the most recent research results and to categorize them to get a rough overview on the situation. For this purpose we will look into the publishing activity of the IEEE (publications are available at [7]).

2.1 Overview

The classification, shown in Table (1) and Figure (1), was done for all the ad hoc networking related publications, conference and journal articles without distinguishing them, published within the IEEE organization in 2001. Categories were selected so that they would describe their contents unambiguously, but still provide detailed and informative knowledge on large scale (i.e the number of classes was tried to keep as small as possible). Power-aware protocols were counted twice, once into the *Power-awareness* category and once into the corresponding category in where the protocol or algorithm was considered. For example, a publication with the topic “A power-aware routing protocol” would be counted into both *Routing* and

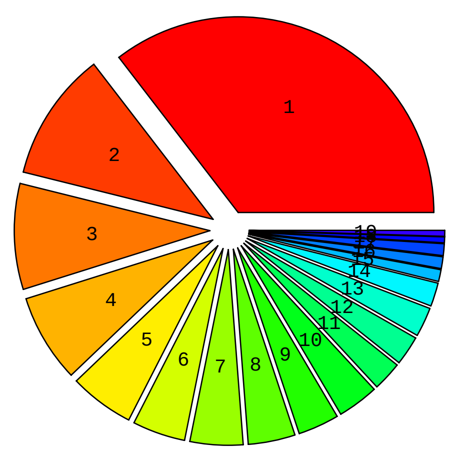

Figure 1: Publications on ad hoc networks within IEEE during 2001, see Table 1 for key

Power-awareness categories.

Four clear facts can be immediately extracted from the data:

- Routing protocols are being studied extensively
- Overall volume of the research effort on AHNs is high (>200 publications a year just in this organization!)
- The spectrum of the topics is wide; ad hoc networking has brought together protocol engineers and mathematicians
- Based on the status of the research projects conducting this work, further rapid development is to be expected at all fronts during the next few years.

2.2 Remarks on the categorization

Care should be taken when interpreting the categorization in detail. Although the major directions are visible, the sample is by no means exhaustive or unbiased, special issues of magazines may have highlighted some topics more than deserved. Furthermore, the classification of papers has some inaccuracies. Compromises were unavoidable because each paper was counted only in one category (with the exception of power-awareness) despite the fact that its contents may have been suitable for another class as well.

3 Open questions

As we saw in the previous section, ad hoc networking has been a popular field of study during the last few years. Almost every aspect of the network has been explored in some level of detail. Yet, no ultimate resolution to any of the problems is found or, at least, agreed on. On the contrary, more questions have arisen than been answered.

This section outlines the major problems remaining to be solved. The protocol dependent development possibilities are mostly omitted and the focus is on the "big picture", on the problems that stand in a way of having peer-to-peer connectivity everywhere in the future. The topics are:

- Scalability
- Quality of Service
- Client server model shift
- Security
- Interoperation with the Internet
- Power control
- Node cooperation
- Support for different routing protocols
- Interoperation with other wireless networks
- Aggregation

This survey here summarizes and complements the approach presented by Perkins [1], with a few additions and several updates. The discussion attempts to sketch the following aspects for the topics: motivation, novel ideas since the publication of [1], and the still remaining problems and their relative importance.

3.1 Scalability

Most of the visionaries depicting applications which are anticipated to benefit from the ad hoc networking technology take scalability as granted. Imagine, for example, the vision of ubiquitous computing where the networks can grow to thousands of nodes. How can be the swarm of control messages carried out in this dynamic environment? It is unclear how large an ad hoc network can actually grow.

Ad hoc networks suffer, by nature, from the scalability problems in capacity. For a rough idea about this, we may look into simple interference studies. In a non-cooperative network, where omni-directional antennas are being used, the throughput per node decreases at a rate $1/\sqrt{N}$, where N is the number of nodes [8]. That is, in a network with 100 nodes, a single device gets approximately one tenth of the theoretical data rate of the network interface card *at maximum*. This problem, however, cannot be fixed except by physical layer improvements, such as smart antennas.

If the available capacity sets some limits for communications, so do the protocols as well. Route acquisition, service location and encryption key exchange are just examples of tasks that will require considerable overhead, which will grow rapidly with the network size. If the scarce resources are wasted with profuse control traffic, it is clear that ad hoc networks will see never dawn in practice. Scalability is an important research topic for the future, not only because of its necessity for ad hoc networks, but also because of the applicability of same ideas in the Internet.

In the protocol design itself, several issues have to be considered with the potential applications in mind. Whereas proactive routing is not scalable in a dynamic environment as such, on-demand protocols allow deploying large networks in the expense of increased route acquisition latency. The minimum route acquisition latency is the product of maximum network diameter and minimum node traversal time for route requests. Correspondingly, demands for short latencies for route acquisition limit the network size drastically. Can this be accepted by the applications? If not, what can be done?

Traditional way of scaling the network has been hierarchical routing, the running of routing and other networks functions on a several hierarchical levels. Hierarchies can be constructed by clustering algorithms which collect nodes near each other into groups. While hierarchy may not be natural for all ad hoc networks, it is one of the very few methods capable of providing any relief to the scalability problem. Mobility and dynamic hierarchy, however, need to be carefully taken into account in order to achieve any practical solutions. Several clustering solutions have already been brought forward recently, e.g. [9, 10]. Some other approaches have proposed also wide-area routing protocols [11] to complement broadcast-intensive local routing. Development of simple rules to cluster nodes and share routing information will remain actively researched.

Routing simulations discussed in the literature have been very small in comparison of the futuristic idea of ubiquitous computing or sensor dust of tens of thousands of nodes. Therefore, large scale simulation studies and also trial deployment are essential to study in the future.

Future research will probably develop scenarios, isolate useful applications, to optimize the trade-off between capacity and scalability in each case separately. For a general solution much remains to be done. Without development in intelligent antennas and multiuser detection, scaling AHNs to thousands of nodes seems a daunting task indeed.

3.2 Quality of Service

The heterogeneity of existing applications in the Internet have challenged the network which is able to provide only best-effort service. Voice, live video and file transfer, to mention the common examples, all have very differing requirements what comes to delay, jitter, bandwidth, packet loss probability etc. Quality of Service (QoS) is being developed to meet the emerging requirements. QoS is a guarantee by the network to provide certain performance for a flow in terms of the quantities mentioned above. QoS routing attempts to locate routes that satisfy given performance constraints and then reserve enough capacity for the flow.

If we consider ad hoc networks as a natural extension of the Internet at the borders where direct connections to fixed infrastructure are unavailable, these applications (voice, live video, file transfer etc.) will exist also in ad hoc networks and so there will also be naturally a demand for QoS. However, the lack of fixed infrastructure in ad hoc networks makes the QoS appear even more challenging problem than ever before. Bandwidth is seriously limited, routes are using links with differing quality and stability. Links are often asymmetrical so that, for example, QoS for telephony (2-way traffic with QoS-demands) may not be achieved by just one route. These facts are often completely ignored by the routing protocols, although the link-state algorithms could be used to find suitable routes if the links are given suitable QoS costs. Alternatively, on-demand protocols can be configured to return only communications paths that comply with the desired parameters.

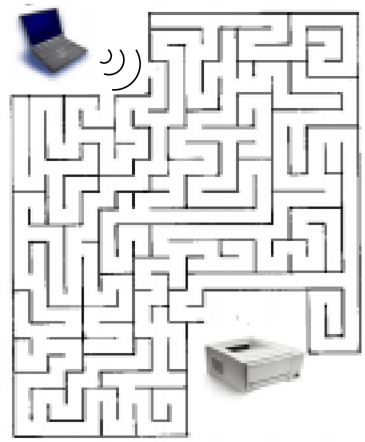

Figure 2: Services can be difficult to locate in ad hoc networks

QoS in AHNs is still largely unexplored area, a good introduction to the field of study can be found from [12]. Issues of QoS robustness, QoS routing policies, algorithms and protocols with multiple, including preemptive, priorities are to be researched in the future. It seems that in ad hoc networks end user may have to “haggle” with the network on the QoS parameters as high quality is frequently not available.

Quality of service cannot be guaranteed for a long time because of the link quality variations due to the interferences etc. Methods to detect and report changes in the connection quality should be investigated in the future. Perkins suggest an addition of a new ICMP message (QOS_LOST) to be defined to inform the endpoints that a new route discovery should be initiated.

3.3 Client-server model shift and service location

In the Internet, a network client is typically configured to use a server as its partner for network transactions. These servers can be found automatically or by static configuration. In ad hoc networks, however, the network structure cannot be defined by collecting IP-addresses into subnets. There may not be servers, but the demand for basic services still exists. Address allocation, name resolution, authentication and the service location itself are just examples of the very basic services which are needed but their location in the network is unknown and possibly even changing over time. Where do services reside (see Figure (2)? Who is administering or maintaining the these services?

In ad hoc some recent proposals have considered integrating route discovery and service location tasks by allowing only particular kind of services to react to the broadcast requests. This approach, however, can be seen to have the following deficiencies:

- Inserting application service discovery into a network layer protocol violates the modular protocol design.
- The client may not be able to specify the required service in a way that the request can be carried on the network layer.
- Authorization can be difficult at the network layer.

Other possibilities are, e.g., using well-known multicast addresses for very basic features, such as DNS. Also protocols for service location have been proposed. Some recent works on this field include [13, 14].

An intellectual challenge related to the service availability problems is the design of distributed network functions. It could be investigated whether and which services (or their locations) could be shared or circulated among nodes? Still the question of who is administering and ultimately responsible for the services remain unanswered.

3.4 Security

Ad hoc networks are particularly prone to malicious behavior. Lack of any centralized network management or certification authority makes these dynamically changing wireless structures very vulnerable to infiltration, eavesdropping, interference etc. Security is often considered to be the major "roadblock" in commercial application of ad hoc network technology [15].

Security requirements depend naturally on the application where they are needed. In cases where all the terminals are "on the same side", such as military or emergency rescue applications, it is enough to get protection against outside interference. In civilian, especially commercial, applications even mere lack of cooperation may be enough to bring the network on its knees. The nodes enter and leave the networks as they wish and links may be using nodes that should not have access to data. How to define membership in ad hoc networks, how to classify nodes to the trusted and the not-trusted ones?

Traditional methods of protecting the data with cryptographic methods face a challenging task of key distribution and refresh. Accordingly, the research efforts on security have mostly concentrated on secure data forwarding. However, many security risks are related to the peculiar features of ad hoc networks. The most serious problem is probably the risk of a node being captured and compromised. This node would then have access to structural information on the network, relayed data, but it can also send false routing information which would paralyze the entire network very quickly.

In [16] the authors discussed the security problems in general and proposed a self-organized public-key infrastructure for ad hoc network cryptography. Key exchanging, however, raise again the scalability issues. Furthermore, defining keys for multicast transmission seems even tougher challenge.

Secure routing was considered in [17], which had an appealing idea of dividing the data on N pieces which are send along separate routes and, at the destination, the original message is reconstructed out of any $(M - out - of - N)$ pieces of the message.

Security is indeed one of the most difficult problems to be solved, but it has received only modest attention so far. The "golden age" of this research field can be expected to dawn only after the functional problems on the underlying layers have been agreed on.

3.5 Interoperation with the Internet

It seems very likely that one of the most common applications of ad hoc networks require a connection to the Internet. By ad hoc network technology the coverage of wireless LAN systems can be expanded and complemented. However, the issue of defining the interface between the two very different networks is not straightforward.

If a node in ad hoc network has an Internet connection, it could offer Internet connectivity to the other nodes. The node could defined itself as a default router and the whole ad hoc network could be considered to be "single-hop" from the Internet perspective although the connections are physically over several hop links. Recently a practical solution for this problem was suggested in [18]. The idea was to combine the Mobile-IP technology with ad hoc routing [18] so that the gateway node can be considered to be *foreign agent* for Mobile IP.

3.6 Power control

Power-aware networks are currently being extremely popular within the ad hoc networking research. The motivation for power-aware thinking for wireless communications is obvious, as summarized in [19]:

- Functional utility – New features and functionality usually costs additional energy. By increasing energy efficiency, devices may meet new user demands without reduced useful lifetime.
- Size and weight – Increased power efficiency can allow smaller and lighter power source.
- Maintenance – Power sources will always need to be replaced or recharged at some point, and the cost for this can vary from inconvenient to prohibitive.
- Environmental – Battery designs contain acids and heavy metals, which must be disposed of properly.

There are two research topics which are partially similar: the maximization of lifetime of a single battery and the maximization of the lifetime of the whole network. The former is related to commercial applications and node cooperation issues whereas the latter is especially of military etc. interest, where the node cooperation is already assumed.

The goals can be achieved either by developing better batteries, or by making the network terminals' operation more power efficient. The first approach is likely to give a 40% increase in battery life in near future (with Li-Polymer batteries) [19]. As to the device power consumption, the primary aspect are achieving energy savings is through the low power hardware development using techniques such as variable clock speed CPUs, flash memory, and disk spindown [20]. However, from the networking point of view our interest naturally focuses on the device's network interface, which is often the single largest consumer of power.

Energy efficiency at the network interface can be improved by developing transmission/reception technologies on the physical layer and by sensing inactivity on the application layer, but especially with certain networking algorithms; MAC, routing and handling of end-to-end connections. In all these approaches, savings are based on intelligently turning off the interface when it is not needed.

Medium Access Control - protocols can be made power-aware by simple rules: when the node has nothing to send or receive, or it overhears a transmission (i.e. the radio channel is busy) it can power off the network interface and wake again after a while to see is there anything to do. This has significant advantages as receiving unnecessary data is surprisingly expensive in terms of energy consumption. One such protocol, PAMAS, is introduced in [21], for which the authors reported up to 70% energy savings.

Just above the MAC-layer reside different topology reduction algorithms. Their premise is that if the network is dense enough, only a subset of nodes is required to be relaying nodes to maintain full connectivity. This means that some of the nodes can be put to a sleep state (such as provided by IEEE 802.11 [22]) only to wake up periodically to see whether there are incoming traffic directly to them. Active nodes form a forwarding backbone in the network, which can be found distributedly as discussed in [23]. This problem is closely related to (minimum) dominating set problem in graph theory.

In routing, one usually tries to maximize the network lifetime. In other words, routes are selected by their transmission energy cost giving the priority to the nodes with full batteries. This way the time to network partition can be maximized distributedly [24]. Furthermore, unicast and multicast routing should be considered separately when considering energy-efficiency due to the broadcast nature of the transmission [25].

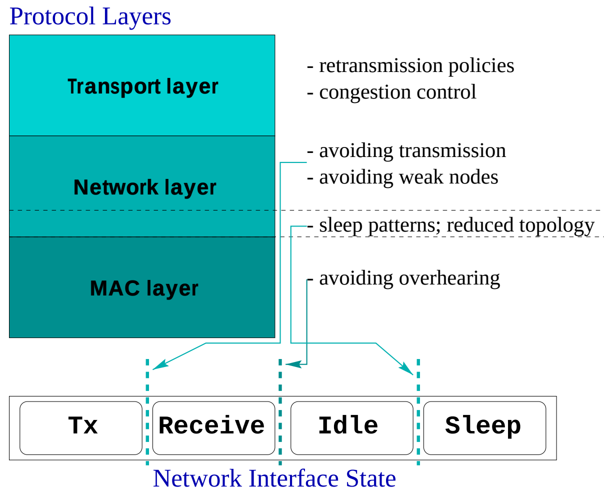

Figure 3: Energy saving methods on protocol layers and between transmitter states

On transport level, collisions and retransmissions should be avoided at all cost. Traditional TCP is badly suited for wireless interfaces as it cannot separate packet losses due to congestion and due to transmission errors, which can be common. An experimental transport protocol for wireless networks is the Wave and Wait protocol [26].

Radio interface of a network device can have four different states (while powered on): transmit, receive, idle, and sleep. The energy consumption of these is highest for transmission and lowest for sleep mode. Figure (3) shows a summary of the energy saving methods as well as the transmitter states between which the corresponding savings are obtained.

Power-aware techniques will remain an important research area in near future on all aspects described above. How these can be combined with the conflicting QoS demands? How can we make sure that a node cannot give false information on its power level just to avoid relaying? Heuristic rerouting to maximize the network lifetime?

3.7 Node cooperation

Closely related to the security issues, the node cooperation stands in the way of commercial application of the technology. The fundamental question is: *Why should anyone relay others' data?* The answer is simple: to receive the corresponding service from the others. However, when differences in amount and priority of the data are existing, the situation is more complex. Surely, a critical fire alarm box should not waste its batteries for relaying gaming data, nor should it denied access because of this behavior.

Encouraging nodes to cooperate may lead to the introduction of billing in ad hoc networks, with a similar idea which was suggested for Internet congestion control in

[27]. Well-behaving network members could be rewarded for the relaying and selfish or malicious users could be charged. Implementation of any kind of billing mechanism, however, is very challenging. These issues are still wide open.

These questions have been recently introduced in e.g. [28], where a simple mechanism based on a counter in each node is studied.

3.8 Support for different routing protocols

If energy costs or other dynamic quantities are to be tracked, there may be significant differences between routing algorithm performances. For certain sensor networks, static node-state based algorithms enable route optimization especially in multicast case, whereas such algorithm would be too cumbersome for networks with mobility.

Dozens of routing protocols have bee introduced, all of which typically perform well in some situations while having significant weaknesses in other cases. Question is, can the heterogeneity of the ad hoc networks be covered by any single routing algorithm?

If no all-round routing protocol can be found or agreed on, the networks have to be capable of supporting several protocols. This can happen so that as a certain number of network nodes detect that their routing is not optimal the network switches to another protocol. When a protocol ceases to be optimal and how can the change be implemented?

Another option is that the network is able to simultaneously support several routing methods. How to define the interfaces and self-awareness?

3.9 Interoperation with other wireless networks

3.9.1 Ad hoc networks

The self-organization of ad hoc networks is a challenge when two independently emerged networks collide. This is an unexplored research topic that has implications on all levels on the system design.

What happens when two autonomous ad hoc networks move into same area? Surely they are unable to avoid interfering each other. Ideally, the networks would recognize the situation and be merged. However, the issue of joining two networks is not trivial; the networks may be using different synchronization, or even medium access or routing protocols. Security becomes also a major concern in these cases. Can the networks adapt to the situation?

A common example; a military unit moving into an area covered by a sensor network could be such a situation; moving unit would probably be using different routing protocol with location information support, while the sensor network would have a simple static routing protocol.

A similar problem arises when a device is powered on at a border of several networks and it has to choose which one to join.

3.9.2 Anytime, anywhere

One of the most important aims of the research on all wireless networks is to provide seamless integration of all types of networks. This issue raises questions how can the ad hoc networks designed so that they are compatible with e.g. WLAN or 3rd Generation cellular networks? Could the other networks extended from last-hop to multi-hop wireless connections using these techniques?

3.10 Aggregation

Finally, there is the question of rationalizing and collecting the research results. Research has been extremely active during the past few years. The pace has been so fast that the big picture is somewhat blurred. That is why there is a need for summarizing research efforts to combine, not just compare, different approaches. The trend is towards more complete ad hoc networking solutions instead of specific protocols in the near future. The first works on this field has been conducted for energy conserving purposes because of its inherent “multilayer”-structure that provides a natural environment for combining different ideas.

There is work to be done to find best possible combinations of MAC, topology reduction, and routing protocols. There is also work to be done in combining preferable properties of different protocols. This will naturally lead to discussion on specific networks, application tailored solutions, as the ultimate ad hoc networking solution is still far away, if it even can be found.

4 Major ongoing efforts

In this section we discuss two very different but comprehensive examples of recent ongoing long term research projects aiming at producing functional ad hoc networks.

4.1 The Terminodes project

The Terminodes project [29] is a 10-year joint effort of seven Swiss research institutes started in 2000. Their aim is to study and prototype a large-scale ad hoc network with the emphasis on the self-organization feature. The network has a two-layer routing system which is based on location information at long ranges while routing traditionally over few hops. Other issues considered so far in this project have been mobility management, GPS-free positioning, cooperation and security.

The project had goals also on higher level of abstraction than just the network design. It is meant to be an intellectual stimulus to find new research challenges, e.g. “how

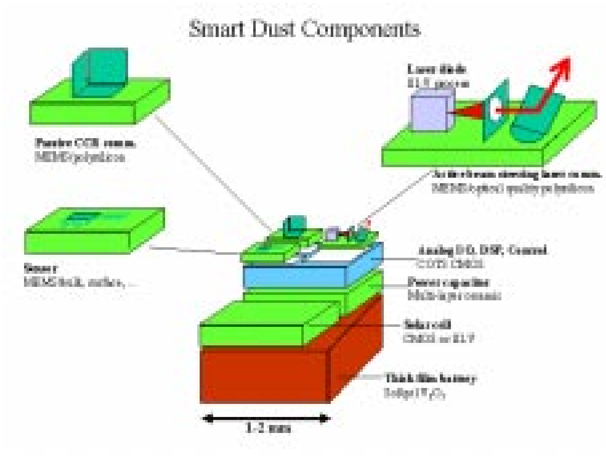

Figure 4: Small sensors using ad hoc radio [30]

do we define a formal model for fair exchange?” [11]. Ultimately the project is a societal vision in which this kind of communication is considered.

4.2 Smart Dust

Maybe the most concrete project related to ad hoc networks is DARPA-funded Smart Dust [30] at the University of California, Berkeley. Smart Dust goals are to design, build and test networks consisting of small sensor nodes (see Figure (4)). The applications include various military purposes, such as battlefield sensor networks, traffic mapping, sensor mine fields, etc. In civilian use these devices can be used e.g. building sensors in earthquake zones. The sensors communicate with RF or optical transmitters and the communications issues (which are not the main theme in the project) raise some interesting questions, see [31].

5 Future view

It is sometimes useful to try to predict the future to get new ideas and see the present day in a more appropriate context on larger scale. Future is unknown, but it is, after all, the result of the actions we take now. In this Section we look into the crystal ball and give scenarios on the future development. How do ad hoc networks evolve? What are the enabling technologies? What kind of applications we are going to see in the near future?

5.1 Going Ad Hoc

There are many open questions related to ad hoc networks applications. Before a public demand for any set of applications can be found, these networks will be deployed in various specialized cases. In the first phase, which can be already foreseen we will have autonomous military and public authority ad hoc networks, which can be used for a very specific purposes. For the most part the networks will be quite small except for the sensor applications, including the millimeter sized sensing networks.

In the second phase, the future cellular infrastructure extensions could be implemented so that ad hoc networking would act as a basis of the whole 4th generation wireless technology. An image of completely unrestricted “anytime, anywhere” communications using this technology seems, however, to belong to the more distant future. Problems with security, authorization and management are daunting indeed in large scale networks. Hence, it is more likely that the technology will be used to augment wireless LAN technology with the limited network size or hops in connections.

5.2 The Revolution?

Assume that most of the problems discussed in this paper are solved and there is a possibility to deploy secure broadband self-organizing ad hoc networks with hundreds or thousands of nodes. What will happen?

The general trend is towards low-level infrastructure and increased end-user responsibility. Being able to freely communicate transfer information with close-by people is, of course, convenient, but it may even have larger societal effects.

On a larger scale, ad hoc networking can very well be the next revolution in the world of communications. It enables local communities to manages their own need for connectivity using their own local resources. The control of the local network will be hence again where it belongs and the ISP era might be coming to an turning point. Why to a call a taxi if you are visiting your next door neighbor or the shop around the corner? The telecommunications business would experience shift from the operators towards both device manufacturers and end-users themselves. Are the operators going to allow this development? Can it be done without their support?

In this local community networking view can be the seed of a completely new approach to communicating with people and henceforth to understanding what it means to be a part of a community. In these local networks many services, such as local web pages, e-mail and telephony, would be free from charge and jurisdiction by remote administrations. Naturally, there would be some privacy concerns in the beginning, but trust inside the community should provide the necessary umbrella for the privacy.

Ad hoc networks have indeed the potential to change how we see the communications world today. For alternative scenarios of the wireless future, where the services stay centralized, interested reader should consult e.g. [32].

5.3 Conclusion

Whereas ad hoc networks will become widely used in military contexts in near future, the corporate world has to continue the daunting search for profitable commercial applications and possibilities of the technology. Meanwhile, the academic community has adopted the new field as a playground to apply their ideas to create something completely new. In all, although the widespread deployment of ad hoc networks is still years away, the research in this field will continue being very active and imaginative.

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