An Approach to Ad-hoc Messaging Networks Using Time Shifted Propagation

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***Abstract*—Many communication devices, like mobile phones and PDAs, are enabled for near field communication by using Bluetooth. Many approaches dealt so far with the attempt to transfer mobile ad-hoc networks (MANET) to the mechanism of the "fixed internet" to mobile networks. In order to achieve liability and robustness of common TCP connections routing algorithm in near field communication based networks become more sophisticated and complex. These mechanisms often do not reflect on the application's particularities.**

Our approach of an ad-hoc messaging network (AMNET) uses simple store-and-forward message passing to spread data asynchronously. We do not aim at the reliability of common internet networks but focus on application specific needs that can be covered by simple message passing mechanism. In this paper we will portray a powerful network by using simple devices and communication protocols on the basis of AMNETs. Simulation results of our AMNET approach provide insights towards speeding up the network setup process and to enable the use of AMNETs even with few participants by introducing a hybrid structure of infrastructure and mobile nodes.

***Index Terms*—ad-hoc messaging network, mobile ad-hoc network, network simulation, time shifted routing, store and foreward message propagation.**

I. INTRODUCTION

During the last few years a growing variety of network services enter the field of mobile communication. Mobile phones are equipped with multiple communication interfaces which provide a potential interconnectedness for various applications. But the underlying networks tend to depend on infrastructures that are bound to stationary devices, like access points, cellular mobile radio, providers which regulate the access to the Internet and the traffic control. In our research we concentrate on a new "message-based" approach. This allows data exchange between mobile devices without the need for a centralized service unit. Data exchange mechanisms base on the Bluetooth standard and follow store-and-forward principles. Categorizing the transferred data into personalized or anonymous messages it is possible to analyze the different requirements in ad-hoc messaging networks (AMNETs) regarding security, stability, and flexibility [1]. This contribution is embedded in research on routing problems [2] between nodes on mobile ad-hoc networks, e.g. common MANETs or mesh-networks [3]. On this basis, we will present the AMNET concept and provide empirical research in this field of ad-hoc networking based on Bluetooth connectivity.

Furthermore we transfer the AMNET concept into practice and research the message transfer behavior in AMNETs. For this reason we set up a simulation environment that allows numeric simulations of message transfers. We are enabled to track the influence of additional stationary nodes that are statically connected. This structure represents a hybrid network of mobile and stationary nodes which speeds up message diffusion compared to scenarios containing mobile nodes only. This is the most important factor concerning a potential diffusion of AMNET technology in reality. This contribution ends with the description of the simulation results and final conclusions

II. ISSUES OF ROUTING IN MOBILE NETWORKS

In this section we will present the basic essentials of the AMNET approach, the ad-hoc platform, based on the IEEE 802.15 Bluetooth standards for wireless local networks (e.g. personal area networks). Firstly, we will concentrate on the issue of addressing and routing messages. Secondly, we discuss the potentials and possible applications for AMNETs.

In recent years a growing number of research has been conducted on routing in MANETs [4, 5, 6] particularly with regard to the limitations of routing protocols [7]. Some reactive and proactive routing algorithms are provided with respect to different situations they are used in. Common protocols show specific vulnerabilities according to scalability, mobility, and network utilization. In growing networks both methods run out of control because scalability is not suitable and depends on the network's structure. With reference to Broch et al. [8] especially unpredictable mobility, network load, and complex topology are the main factors that retard the effectiveness of the algorithms in scaling networks. Networks with fast moving nodes often change their topology. These "vivid" networks rely on mechanisms to find routes that are too complex to grant enduring topologies [9].

These highly dynamic MANETs which contain a large number of network nodes make great demands on ad-hoc routing protocols [7, 10]. In practice a trade-off between stability and the maintenance bandwidth overhead limits the effectiveness of those settings in growing scenarios. Especially reactive algorithms tend not to be usable within huge networks and reactive routing algorithms tend not to scale well in large settings [11, 12].

Promising improvements are suggested by the work of Hass et al. that combines proactive and reactive paradigms to a hybrid routing algorithm, such as the "Zone Routing Protocol (ZRP)" [13], which proves efficiency in various environments. With respect to a remarkable increasing complexity of the cutting-edge MANET routing algorithms which is the main obstacle for implementing and using them in practice we follow an approach in an other direction: Keeping routing as simple as possible considering messages as the point of interest and deny the ambition to bring all internet features to mobile networks. AMNET concentrates on mechanisms to provide a best-fit solution for certain application's needs in vivid network environments.

III. TECHNOLOGY BACKGROUND

We coin the term AMNET (ad-hoc messaging network) for our approach in order to describe a virtual network infrastructure which does not provide any guaranteed reliability for attached network services. Although such limitation does not meet the requirements for a vast number of applications several scenarios with lower demands on transport reliability would benefit from the AMNET approach.

AMNET is based on an ad-hoc store-and-forward procedure for data message interchange. Message forwarding in AMNETs is not subject to time constraints, or real-time message routing respectively. This reflects AMNET's store-and-forward character. As a consequence, message routing and forwarding is significantly less complex than in traditional MANET scenarios.

Bluetooth is AMNET's currently employed wireless networking standard, which turns out to be widely available in mobile phones and small computers, like PDAs, and consequently carries potential for a dense network of AMNET-enabled nodes. Other wireless network technologies, e.g. IEEE 802.11 techniques, may be used for the set up AMNETs as well. However, there are no implementations unitl now on these devices.

A. AMNET Concept

In contrast to conventional mesh networking concepts which achieve the implementation of stable and reliable networking clouds as the foundation for common IP-based applications, we focus on the deployment of mobile devices for spontaneous data transmission without a formal infrastructure. Hence, message exchanges do not rely on end-to-end connections between the involved nodes. This highly reduces or even eliminates the route maintenance complexity compared to mesh networks. Table 1 compares the AMNET and MANET approaches regarding routing and network capabilities.

The basic concept of AMNET focuses on the message exchange between two or more nodes being neighbors in the sense of wireless radio range. Moving nodes go along with changing neighbors which than constitute a network which is characterized by receiving messages, storing, 'carrying' over a distance, and delivering them asynchronously. Although no persistent end-to-end connections exist, this highly partitioned network offers potential for applications that can handle or even benefit from these particularities.

B. AMNET-Comparable Applications

There are existing situations and settings which are built upon the particularities that are pointed out by AMNET implementations. In these applications the problems are addressed specifically. Here are some examples of AMNET principles used in different existing environments:

MANET	AMNET
Routing properties	
Real time message routing	Time-delayed message exchange
Directed message addressing	Message exchange with multicast patterns
Source-destination addressing	Category-based message filtering
Proactive/reactive routing protocols	Store-and-forward principle
Non-optimal performance in dynamic networks	Inherently based on dynamic networking properties
Single route per message	Multiple routes per message
Network properties	
Scaling issues distance independent	Focuses on localized communication (scaling is subject to further research)
End-to-end connection infrastructure	Loose coupling of nodes
Consistency of nodes and relations (e.g. routing tables)	No network based addressing mechanisms
Network properties mostly application-transparent	Applications according to network properties (anonymous, profile-based)
Deterministic and reliable routing	Fish-eye routing

table 1. Comparison AMNET – MANET

Cambodian motorbike e-mail: In remote Cambodian villages, motorbike messengers fetch and deliver e-mails daily, using wireless technology, while passing by rural schools and a central satellite internet uplink [14]. Sending and receiving messages in a store-and-forward method is a characteristic of AMNET implementations which could connect mobile nodes in isolated environments temporarily.

Loose sensor networks: Well known representatives of this type of wireless ad-hoc networks are implementations like smart dust, home monitoring systems, industrial surveillance networks and others. In dense temperature sensor networks for example, the information finds its way throughout the network to a destination and depending on routing implementation the data transferred may be aggregated in order to save capacity of each node, as evaluated in [15].

Locations Based Services (LBS), Who-is-around-lists: Deployed LBS applications depend on centralized databases providing localized information. In AMNET, LBS could be adopted when accepting a certain degree of haziness, since message validity can be coupled with the count of forwarding nodes, providing a 'proximity-based' information service without the need for central service providers or information repositories.

IV. IMPLEMENTATION

A. AMNET Architecture

We implemented a prototype for mobile phones which utilizes message exchange via Bluetooth. In accordance with typical layer models, as known from the ISO-OSI layering, the architecture has been designed as follows (fig. 1).

All underlying devices are Bluetooth-enabled. The AMNET scope does not cover the actual link layer, thus it is possible to use different techniques of wireless physical communications, e.g. IEEE 802.11 or Zigbee. The requirement for a message repository for data storage is an AMNET inherent part. Configurable message filters control the access of applications towards the repository content. Message properties, set by the various applications by means of message filters, allow for certain message exchange rules between the mobile devices. Apart from that, the applications have direct connection to the message exchange process itself, indicated through the comprehensive block “message exchange protocol”. The prototype uses the Java Platform 2, Micro Edition. For interacting with the device’s Bluetooth stack, we use the Java API for Bluetooth (JSR-82). Along with this prototype, a program interface has been implemented that

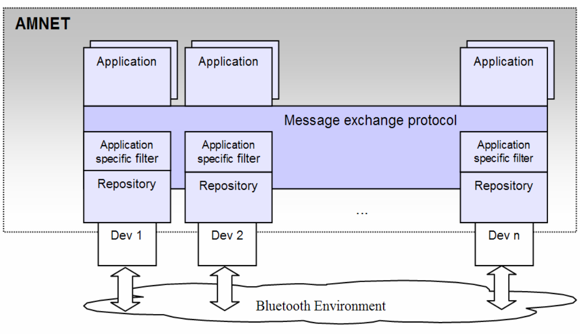

figure 1. AMNET- Architecture

General Header	Message ID	Application ID	Hop Count	Sending Time
Application Header	Category	Addressing	Validity	
Application Data	Payload			

table 2. Message Structure in AMNETs

allows simulating numerous mobile devices moving within a simulation environment, which provides a test bed for message exchange and routing behavior.

B. AMNET Protocols

Messages are the central objects in AMNETs. The message format varies among the layers in the AMNET architecture.

Figure 2 shows the general structure of messages transmitted between AMNET nodes. The message header (“General Header”) is followed by application-specific fields (“Application Header”), and finally by the application-specific message payload itself. The different parts of a message are handled by different components of the AMNET architecture. The general header is analyzed by the message repository, the evaluation of the application header takes place in the application specific filter connected to the repository and the message data are passed through to the application. The following steps are performed when a message is received via the network link:

Newly received messages are added to the message repository, if not yet in there. Rejected messages are ignored from further processing within the actual component. That means that messages rejected by the application specific filter are not passed on to the application but still exist in the message repository. Thus, such messages still will be passed on to other nodes in range even when they are not relevant to the nodes own applications. This is part of the AMNET store-and-forward concept. Nodes store messages for a maximum amount of time and deliver them to close-range nodes, with storage time and maximum hop count as limiting factors. That prevents messages to live forever within the

Repository	1. Message ID exist in repository? Reject! 2. Application ID not installed? Reject! 3. Pass to application specific filter based on application ID
Application Specific Filter	1. Validity parameters invalid according to application settings? Reject! 2. If application supports addressing: Address does not match application instance? Reject! 3. If category filtering is enabled: Category does not match application category? Reject!
Application	1. Application specific handling

table 3. Actions on Message Receiving

network and congestion can be reduced. Messages can be identified by sender address, message payload message authentication code (MAC), hop count, among others. This establishes a multicast-like procedure in order to synchronize message repositories of nodes within a certain distance.

Repository organization and message storing are key areas within the AMNET concept. Since the main platform envisioned for AMNET consists of mobile phones and other small digital devices with considerably limited storage and computation capabilities, the repository handling has to be carefully designed, along with message caching and efficient storage techniques. Corresponding to existing approaches for data management in explicitly resource-limited systems, a filtering system has been implemented [7, 16], which can also be used and extended by applications for various message filtering purposes.

C. Devices

The AMNET approach inherently requires a large number of AMNET-enabled devices in order to provide effective message transfers. With a growing density of AMNET nodes, message delivery speed and reliability increases considerably. It should be noted that real-life Bluetooth implementations in mobile devices often do not implement all properties required in the Bluetooth standard, and specifically do not allow multiple simultaneous Bluetooth connections [1, 17], which stresses the need for a high AMNET node density. There are some restrictions to the devices itself the application has to handle.

A serious problem for the attempt of message propagation without user interaction is the device-specific implementation of Bluetooth security activities. Many operating systems, e.g. Symbian, do not allow programs to listen for incoming Bluetooth connections without asking for acknowledgement each time. In this environment a quiet and transparent passing through is not possible.

Additionally, standard mobile phones pose considerable limitations on J2ME applications. Especially low-end consumer devices do not accept applications that use more than 512kB of memory. This is because of the CDLC specifications and has been empirically shown by Huopaniemi et al. [18].

D. AMNET Simulation

As aforementioned, the number of participating users represents a critical factor concerning the success of AMNETs. Only a sufficient amount of network nodes guaranties the successful deployment of applications that deliver messages by diffusion. The common impact of network externalities has been discussed on the basis of various technologies with regard to the introduction of new standards [19].[1]

One main factor to accelerate technology diffusion as described by Erber et al. is to reach a critical mass of users. The typical network effects [20] apply as well in AMNETs. Special problems result in the initial (phase) when only very few users participate. Previous research on positive external effects assumes a small increase of benefit for every user when new participants join even throughout the start phase [20]. This is not the case with AMNETs where a certain fixed quantity of existing nodes is mandatory for the message transfer. To reach an initial critical quantity of notes stationary connected network participants could be implemented.

To analyze network effects within AMNETs we implemented a simulation environment which is capable of displaying a varying number of mobile nodes. The dynamically designed round-based model provides information about the number of rounds necessary until a message is spread to a certain quota of mobile nodes. In round 0 one node at random receives a message which is to be transferred to other nodes in his simulated radio range. The following parameters and data describe our simulation environment:

- Simulated area: 6 * 4 km urban area (Berlin Mitte, Germany)
- Pseudo-realistic urban landscape using street maps
- Participants move on streets and open spaces
- Pace rate of the simulated nodes matches walking speed, which is up to 3 km/h
- Radio range of participants is restricted to 10 m (according Bluetooth standard)
- Round-based simulation: One step of simulation equals one second.
- Connection to other devices is only established after 5 rounds of mutual visibility (according to tests regarding Bluetooth discovery times)
- Up to 3 message transfers per node per round
- Different patterns of movement can be assigned to network participants

The virtual environment can be replenished by mutually connected stationary nodes.

E. Simulation Results

Figure 2 shows a screenshot of the simulation. Blue nodes symbolize network users without messages, red nodes have already received messages, and yellow nodes represent permanently connected stationary nodes (infrastructure nodes). These nodes are capable to synchronize messages with mobiles nodes in the vicinity. After receiving a message from a stationary node, the message will be forwarded to all other stationary nodes into the same or another network segment.

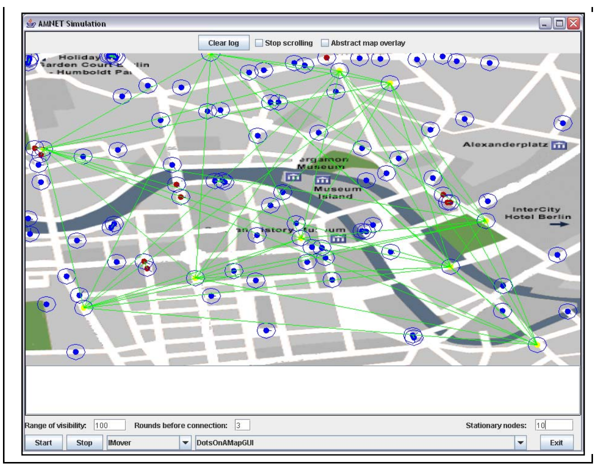

figure 2. Simulation software

[1] A discussion concerning well-known problems in networking environments, e.g. free-rider behaviour, tippiness effects or the existence of malign nodes is omitted here.

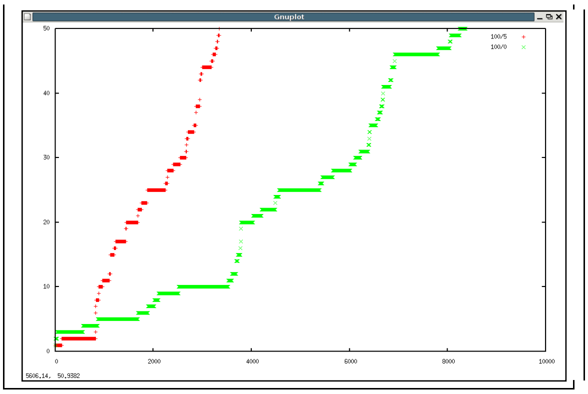

figure 3. Results with 100 mobile nodes

Figure 3 shows the distribution of the initial message in the network in relation to the number of rounds. The green values represent the progression without stationary nodes while the red values show the message distribution in an environment with 5 additional randomly positioned stationary units. To research the effects of stationary network participants, their quantity was varied in different simulation runs, and the speed of message distribution is documented.

Figure 3 shows the result of two test scenarios. However, we performed a multitude of simulation runs with varying parameters. Our analyses show that the number of nodes determines the acceleration of message distribution. Moreover, stationary nodes speed up the message transfer irrespective of the quantity of mobile nodes. The “geographical” positions of the stationary nodes are important. If stationary nodes are close to each other and mobile nodes are spread widely, the accelerating effect of network of message transfers are less significant. Stationary nodes are especially effective when only few mobile nodes are involved. With an increasing number of mobile nodes, stationary ones lose significance. On the basis of our simulation results it is possible to calculate the optimal quantity of stationary nodes in proportion to a varying quantity of mobile nodes.

V. APPLICATIONS IN AMNETS

A. Categorization

Applications which utilize the described AMNET network fall into three categories based on their levels of authentication and authorization. These levels range from complete anonymity to verified authorship and addressees. As far as identifications and authorizations are not part of the AMNET platform itself it can be supported by the application specific filters. An authorization scheme may support this function. Additionally, addressing can be achieved through application specific filters that check for an ID or address specific to the application instance. The address types may range from category-based messages to specifically addressed messages with different hop ranges. Table 2 shows applications with different authorization and addressing concepts. The current focus lies on single and multi-hop non-addressed but category-based messages (marked gray in table 4). since the addressed scenario has been subject to comprehensive research [21]. The described store-and-forward mechanism with hop count limitations can be easily used to control the message distribution range.

Anonymous Services	Electronic Bulletin Board	Location-Centric Advertisement	Client-Server-Architecture
Profile-based Identification	E-Learning, Community-based Applications (Reputation Systems etc.)	File-Sharing	General Network Applications, Portals
Authenti-cated Transactions	Traffic Congestion Information Systems, Emergency Information Systems	E-Payment	VPN, Business Transactions
	Category-based Messages (multi-hop)	**Messages with Specific Addressees (single-hop)**	**Messages with Specific Addressees (multi-hop)**

table 4. Applications within AMNETs

The authentication and personalization levels are implemented on top of the AMNET data structures, with various implications for the AMNET network protocol. The existing prototype implementation is sufficient for illustrating the basic functionality and operation of AMNETs, but requires further development for enhanced studies, mainly in the area of applications.

B. Applications

Electronic Bulletin Board – *Category-based routing and anonymous messaging.*

An electronic bulletin board can be used to send messages addressed to all individuals in a specific area (non personal messages). Receiving posts from bulletin boards can be restricted by defining different categories which one can subscribe to. For example, an electronic bulletin board can be used to signalize specific interests or offers to other people nearby. By supporting multiple node hops messages can be sent to a wide range of individuals. Limiting the number of valid hops can be used as an instrument to control the range of the local area, where this message can be received. The diffusion of messages can be accelerated by the use of stationary nodes as our simulations show.

Community Features – *Combining who-is-online lists with position based information.*

Community services such as configuring a personal profile using who-is-online lists or complex reputation systems can be provided by mobile ad-hoc networks, e.g. for virtual communities [22]. Generating social network effects can be used as one key element to increase diffusion of the described standard. To send a self-administrated personalized user profile can be used in many ways, e.g. to meet people with special interests or to be informed if one of the who-is-online list is in the current local area.

An Environment for Ubiquitous, Pervasive, Mobile E-Learning

To meet the requirements for ubiquitous e-learning [23] a technical solution for the exchange of learning content can be found in ad hoc messaging. Hence, AMNETS are applicable to exchange messages and learning objects among participants. This process does not even require any user interaction, a connection could be established and information could be shared automatically [1]. With the combination of decentralized synchronization processes, fixed synchronization points (static AMNET nodes) a platform can be created that covers all issues for modern mobile e-learning environments, which already showed by the authors in an applied AMNET project [24].

VI. CONCLUSION

Our research in the field of AMNET suggests that beneficial message communication can be introduced for an ad-hoc network that serves many applications. AMNETs allow a fast diffusion of messages in dense networks with a given number of hops.

In contrast to other technologies this architecture requires a critical mass of nodes to be successful. It is a particularity of AMNETs that a certain number of participants are needed to gain a benefit from passing messages to others. Stationary nodes can help to overcome these problems and reduce the barrier for setting up an AMNET system.

Within the scope of further research new AMNET prototypes will be developed. The presented simulation environment will be expanded in order to gain more information to increase the efficiency in AMNETs using hybrid networks that consist of stationary and mobile nodes.

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