Report of the MiNEMA PhD Workshop: *Scalable Communication Protocols in Mobile Networks*

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1 Workshop Participants

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2 Meeting Description

The participants met for the workshop at INESC-ID in Lisbon, Portugal, on July 28-31 2008. The program consisted of one day dedicated for the formal presentations of the recent and on-going works of the students, another day for a brainstorming and a third day for consolidating ideas and establishing pair wise interactions between the participants that identified collaborative opportunities. On the last day the structure and much of the content of the technical report described in Appendix A was produced.

The presentation program was the following:

Presenter	Title
José Mocito	Mobility-Assisted Publish-Subscribe
Raphaël Kummer	A structured overlay for MANETs and the "Freemote" system emulation framework
Adrian Holzer	Pervaho: a framework for building mobile ad hoc applications
Marcel Cavalcanti	Structured P2P over Wireless Multi-hop Networks
Gabriel Kliot	Probabilistic Quorum Systems in Wireless Ad Hoc Networks and other research topics
Denis Rochat	Power-efficient gossiping in multi-hop ad-hoc networks
François Vessaz	Six-shot Broadcast, a location-based broadcasting algorithm for MANETs

3 Produced Outcome

MiNEMA PhD Workshops provide a great opportunity for PhD students to get familiar with other research topics in the field of middleware for mobile networks and to foster future collaboration opportunities between the participants. It is therefore reasonable to expect that several of these opportunities are identified during the workshop and that collaborative work is planned in order to achieve these goals.

The workshop participants decided that, other then the expected collaboration plans, it would be relevant and useful to produce a document that expresses part of the knowledge exchanged during the meeting. Such a document could be used in the future as a starting point for some of the collaborative work, and also serve as a small part of the set of scientific results that the participants foresee.

The document produced, provided in Appendix A, takes the form of a technical report. The document provides a description of the characteristics and limitations of the most relevant categories of mobile networks and the most relevant communication paradigms used to build distributed applications in those networks, thus motivating the need to adapt the realizations of the latter to the characteristics of the former.

4 Future Collaboration

We have identified a number of research opportunities:

- **DHTs in MANET**: The first part of this collaboration will be to try to better understand the behavior of DHTs in MANETS and to model the influence of certain parameters (i.e., cache size, cache lifetime, number of distinct shortcuts in the logical space, ...) on those systems. In particular, we would like to analyze the lookup path length versus the memory of the routing tables (i.e., their size or number of entries). We will try to model the influence of the shortcuts in the DHT logical space that are provided by the physical neighbors on the length of the lookup path. In the second part, based on the above analysis, we propose to develop a new approach on how to select and manage the cache entries to improve the lookup and to reduce its average path cost. Possible caching strategies include (but are not limited to) caching according to harmonic distribution (inversely proportional to the logical distance on the ring), trade off between the logical quality of the shortcut and its physical cost, attaching confidence probabilities to the cache entries based on the last validation of the link. (Raphaël, Gabi, Marcel)

- **Location-based Pub/Sub: multicasting events using a DHT**. In this research, we want to evaluate the performance of using a DHT for routing events to subscribers compared with our current implementation which uses a Counter-based Multicasting scheme over a Directed Acyclic Graph. (Raphaël and Adrian).

- **Location-based Pub/Sub: a real life implementation for Meshnets**. In this work, we want to investigate and evaluate the possibilities of devising a location-based publish/subscribe service in the context of a Mesh Network. (Adrian and Marcel)

- **Location-based Pub/Sub: a hybrid strategy (pub-centric / sub-centric)** Two radical strategies for implementing publish/subscribe system in MANETs are either to broadcast publications and let the subscribers perform the matching (publication-centric strategy), or broadcast subscriptions and delegate the matching to publishers who will route the matching events to the interested subscribers. The idea of this work is to investigate a hybrid approach that could offer the best of both world (Adrian, Marcel and José).

- **(Location)-based Pub/Sub: target opportunistic networks**. The idea of friendship publishing and the idea that forwarders should store and rebroadcast events in order to overcome partitions and use geographical information and mobility patterns to choose adequate message relaying nodes (Adrian and José).

A Scalable Communication Protocols in Mobile Networks

Scalable Communication Protocols in Mobile Networks

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Abstract

In this report we provide a categorization of mobile networks based on their connectivity and survey a number of communication protocols common in these networks. We further argue that any such communication protocol must be specifically adapted to the characteristics of the network.

1 Introduction

Modern mobile networks encompass a rich set of environments and devices with heterogeneous characteristics. Some assume that all the nodes in the network have the same responsibilities, while others assume role heterogeneity. Some assume random and/or unpredictable mobility patterns, while others consider a constrained physical environment that limits mobility possibilities.

Distributed applications rely on different communication paradigms to offer their services. Such paradigms have different requirements regarding device resources (e.g., storage or location-awareness) and communication dynamics (e.g., peer-to-peer or broker-based).

In order to devise or implement any scalable communication protocol for mobile networks the researcher and/or developer should be well aware of the characteristics and limitations of both the mobile network environment and the used communication paradigms.

This report provides an overview of the most common mobile networks and communication paradigms, giving insights on some of the challenges involved in the development of solutions that combines these two realms. Additionally, it describes recently applied solutions that illustrate the need for adapting the implementations of the communication paradigms to the network environment in which the applications will be executed.

2 Mobile Networks

The notion of mobile network encompasses several different kinds of networks, such as mobile ad hoc networks, mesh networks, vehicular networks, sensor networks, and opportunistic networks.

In the following sections we will briefly describe each of these environments, highlighting some of the most relevant characteristics and limitations.

2.1 Mobile Ad Hoc Networks

Mobile ad hoc networks *(MANETs)* are networks composed of mobile *nodes* communicating with no fixed infrastructure. Each node has a radio transmitter (e.g., IEEE 802.11 WiFi) that is equipped with an omni-directional antenna and is capable to transmit in a zone around it, the *transmission range*. All the nodes in the transmission range of the node are called its *neighbors* and are able to receive the messages that the node sends.

Since nodes are mobile, neighborhoods change over time as nodes get in and out of each others transmission ranges. In a MANET, we expect the nodes to be eventually connected, but due to node's mobility, the topology is always changing and the network may temporarily partition.

Communication between neighbors is straightforward, as every message transmitted by a node is received by all neighbors, thus no routing is necessary. Communication with nodes located outside node's neighborhood is more challenging, since it implies *multi-hop* messages diffusion, where the message must be forwarded by one or more intermediate relays between the sender and the receiver.

Therefore, MANET nodes are challenged by their limited resources (such as battery power, bandwidth or storage capacity) and mobile characteristics. Hence, message transmission protocols targeting MANETs must be specifically designed to save those limited resources.

2.2 Wireless Mesh Networks

Wireless mesh networks (WMNs) consist of mesh routers and mesh clients, where mesh routers have minimal mobility and form a backbone. Mesh routers provide network access for both mesh and conventional clients. WMNs are also known as 802.11s networks, and they are a viable and inexpensive alternative for increasing the coverage of a traditional, single-hop wireless LAN (WLAN).

In WMNs, mesh routers communicate with each other wirelessly, forming a pure wireless, mesh based access network of meshed relay nodes (MRN). Mesh gateways (MG) provide Internet connectivity. Standard mesh clients attach to MRNs, which forward packets via other MRNs to other meshed clients or through MGs to the Internet. The wireless backbone comprised of MRNs and MGs is similar to a static ad hoc network, which is also connected to the Internet via gateway nodes.

The benefits of WMNs include ease of deployment and extension, where MRNs can be dynamically added. As in MANETs, WMNs enable wide coverage, resilience, and reduced cost for Internet access. A typical use case is a neighborhood meshed network, where most houses have a MRN, but only few provide Internet connectivity via MGs, thus tremendously reducing the cost of Internet access. Mobility depends on the type of mesh nodes.

A major problem is a scalability of WMNs. 802.11s based WMNs use 802.11 basic MAC layer access method DCF, and thus suffer from the same intra and inter-flow interference of multi-hop forwarding as in a standard MANET. Techniques such as multi-radio and multi-channel solutions minimize that problem while performing routing and access functionalities. This enables separation of two main types of traffic in the wireless domain. While routing and configuration are performed between MRNs, the access to the network by the end clients can be carried out with a different radio. This significantly improves the capacity of the network. On the other hand, in ad hoc networks, these functionalities are performed in the same channel, and as a result, the performance decreases.

2.3 Vehicular Ad Hoc Networks

Vehicular mobile ad hoc networks (VANETs) are a subset of MANETs targeting inter-vehicle communication. The main particularities of such networks are the speed of nodes, which is higher than usually expected in MANETS and the mobility model, which is more predictable in VANETs since vehicles move along predefined paths (roads). The speed of nodes implies frequently changing topologies with frequent partitioning. Another important characteristic of VANETs is the fact that their resources are abundant since they can rely on vehicle batteries as a power supply. Applications for VANETs can be categorized in two groups: safety and comfort. Safety applications are used to warn other vehicles of collisions, road obstacles and assist drivers in lane changing maneuvers. Comfort applications include, among others: Internet access, traffic information and navigation assistance. The focus of implementing services for safety applications is on reducing delivery time and increasing reliability (QoS), whereas in the case of comfort applications, the focus is on increasing efficiency and avoiding message collisions.

2.4 Wireless Sensor Networks

A wireless sensor network (WSN) is a network consisting of devices spatially distributed in the space. Sensor nodes have low battery and storage capacities, the devices communicate via a wireless protocol and are in general not able to move. This non-mobility implies that the topology of such networks can be pre-configured to avoid partitioning and allows considering a zero change rate. Data communication is multi-hop. Therefore, a delay must be taken into consideration.

2.5 Opportunistic Networks

Opportunistic networks (OpNETs), also known as Delay Tolerant Networks (DTNs), differ from other traditional networks, like MANETs or WMNs, by relying mostly on the mobility of nodes and topology changes to provide communication capabilities. Moreover, no assumptions are made on the network connectivity, which characterizes these networks as mostly partitioned and inherently delay-tolerant. Also, it is expected that a significant proportion of nodes in the network are in movement.

In opportunistic networks nodes are only able to communicate when they are in a *transmission range* of each other, and routing can only be performed by *storing* and *carrying* messages until the nodes are able to forward them to other *carriers* or the respective *destinations*. Every node can be a *carrier* for any given message, although it's not mandatory that every node performs this task. Unless some special assumptions and/or optimizations are made, nodes are considered to be always part of the network, as it is impossible to accurately determine if the absence of interaction with any given node is due to a failure, voluntary disconnection or simply since its own movement trajectory does not intersect the one of any other node.

Resource-wise, opportunistic networks usually require significant storing capabilities on the *carrier* nodes, which is always an important concern in the development of communication protocols for these networks.

2.6 Summary

We classify mobile networks in five different groups; mobile ad hoc networks, wireless mesh networks, vehicular networks, wireless sensor networks, and opportunistic networks. The varying characteristics of the different networks sometimes make it difficult to compare them directly. Therefore, Table 1 summarizes the different network groups described in the previous sections according to the network degree of connectivity level (Strong, Expected, and Weak) versus mobility, topology assumptions, node type, network partitioning, network change rate, and end-to-end delay. Table 2 also provides a comparative analysis on the expected connectivity and resource availability in each type of network environment.

Connection level	**Strong**	**Expected**	**Weak**
Network type	WMN WSN	MANET VANET	OPNET
Predefine node roles	•		
Mobility	restricted	•	•
Topology assumptions			
Node type	pre-configured	emerging	emerging
Network partitioning	none	occasional	frequent
Network change rate	none	medium	high
Time assumptions			
End to End Delay	fn of hops	fn of hops	fn of mobility

Table 1: Mobile network connectivity overview

Connection / Resource Storage/Battery/Bandwidth	**Reasonable**	**Limited**	**Scarce**
Strong	WMN		WSN
Expected	VANET	MANET	
Weak		OPNET	

Table 2: Mobile network overview

3 Communication Paradigms

Different communication paradigms have been proposed to achieve tasks like information distribution and lookup in these different, previously presented, mobile networks. Those communication paradigms have to be adapted to the mobile context with frequent topology changes and the lack of a well defined infrastructure supporting the communication among the network's nodes.

Indeed, suitable approaches require all the nodes to jointly collaborate in order to route messages through the network in a scalable and efficient way, while avoiding unnecessary communication and minimizing the network congestion.

Below we present a number of distributed paradigms to reach all the nodes of the network (*Broadcast*) or only a defined subset of them (*Multicast* and *Publish/subscribe*), as well as a decentralized and efficient lookup algorithm (*Distributed hash table*).

3.1 Broadcast

Broadcasting is a basic task in network communication. Its goal is to transmit a message from one node of the network, called the *source*, to all other nodes. Broadcast is very useful in mobile networks, e.g., for data dissemination and routing protocols, and it can be easily implemented by flooding. However, flooding is usually very inefficient as it generates a significant amount of messages and interfering radio communication.

Another approach to provide a broadcast primitive is to select a special subset of the nodes in the network to forward the messages in order to provide complete coverage. However, this special subset must be computed every time the network topology changes, which can happen very frequently in mobile ad hoc networks, thus also making this mechanism very costly.

Therefore, a special form of broadcast, called *Reliable Broadcast* (*RBC*), can provide strong and important guarantees to the receiving nodes. Reliable broadcast requires that all correct (non-failed) nodes deliver the same set of messages, and that this set includes all messages broadcast by correct nodes, but not spurious messages. Formally, RBC protocol must satisfy the following properties:

Validity: If a correct node broadcasts a message m, then it eventually delivers m.

Agreement: If a node delivers a message m, then all correct nodes eventually deliver m.

Integrity: Every node delivers at most one message m, and only if m was previously broadcast by the associated sender.

In addition, probabilistic broadcast protocols reduce the amount of traffic sent by flooding, allowing every node to rebroadcast a message with a fixed probability p. This probability should be set such as to guarantee delivery by all nodes. Probabilistic broadcast is a very promising solution, because it does not depend on any specific topology and generates significantly less messages than flooding.

3.2 Multicast

Multicast is a group-oriented communication primitive that provides one-to-many delivery semantics. Nodes register in multicast groups which are identified by a network address that can be used to assign messages to the group. Groups are composed of one or more nodes and, depending on the reliability guarantees provided by the protocol, every message sent to the group is delivered to some or all the nodes in the group. There are several applications where a multicast service is useful, like collaborative applications or audio and video streaming, where the cost to send messages to multiple recipients can be greatly reduced when compared to other alternatives like using multiple unicasts (one message for each recipient) or broadcasts. On the other hand, it can also be a costly service due to the amount of information exchange required to maintain an updated group membership, which can significantly penalize the performance of multicast protocols in mobile networks.

3.3 Publish/Subscribe

The Publish/Subscribe paradigm allows one-to-many message diffusion with loosely decoupled participants, i.e., allowing them to communicate in an anonymous and asynchronous fashion. The basic concept underlying publish/subscribe is to view interacting entities in two roles: a first role, that of a *publisher*, consists of generating events, and a second one, that of a *subscriber*, consists of advertising interests in particular kinds of events. The goal of a publish/subscribe service is to trigger notifications on those subscribers, whose interests match the given event, upon occurrence of an event.

Typical publish/subscribe systems include *topic-based* and *content-based* systems. In topic-based publish/subscribe systems, events are associated with a topic and are selected solely on that topic. This is quite similar to a multicast service with multicast groups represented by topics. Content-based publish/subscribe systems offer a finer event selection based on the relevance of their content.

3.4 Distributed Hash Tables

Distributed hash tables (DHT) rely on directed search protocols to efficiently locate peers responsible for a given key. They basically require a small number of communication stages to locate a key, thus generating little traffic. An appropriate implementation of DHT would guarantee that lookup always succeed if the desired file exists in the system. (i.e., no false negative).

Distributed hash tables are structured solutions that build a logical overlay above the physical networks. Unique keys identify the participating nodes and the data items. The nodes are placed in the logical space according to their logical key and files are mapped to nodes using some predefined hash function (usually, nodes are responsible for the files having the smallest logical distance with them accordingly to a defined proximity metric).

The different DHT designs mostly differ by the way they build and maintain the logical space and perform lookup. The keys of nodes and files are usually provided by hash functions like SHA-1.

4 Applied Solutions

In the previous sections we have presented different types of mobile network environments and communication paradigms that can be used to support distributed applications. The challenges of each network setting will determine the solutions used to provide these paradigms, and usually no solution is able to perform well in all settings.

In this section we provide a description of a number of applied solutions that were developed taking into account one or more of these environments. Therefore, it presents an insight on some of the issues that need to be taken into account while bringing the communication paradigms (Section 3) to mobile networks (Section 2).

4.1 Reliable Probabilistic Dissemination

RAPID (Reliable Probabilistic Dissemination in Wireless Ad-Hoc Networks) is a protocol for Reliable Broadcast in MANET. In their paper [9], the authors first show that all previously used techniques to achieve Reliable Broadcast in MANET may fail to satisfy the agreement property of RBC in certain conditions (mainly due to the usage of unreliable wireless links in ad hoc networks or under certain topologies). The consequence is a need for a technique that will ensure high reliability under any condition.

RAPID protocol rises to this challenge by combining 3 other known techniques to provide Reliable Broadcast with low cost. The key observation is that the correctness of this protocol (an agreement property of RBC) is ensured due to the ability to use reliable links when needed. This is achieved either by using unicast with acknowledgement or broadcasting indefinitely. The efficiency of RAPID is provided only in certain "normal" topologies, in which a more efficient and low cost communication primitive (probabilistic broadcasting), combined with a number of optimization techniques (overhearing and counter-based scheme), is used.

RAPID includes three phases: probabilistic forwarding, a counter based corrective deterministic mechanism, and a lazy gossip. In the probabilistic forwarding phase, the retransmission probability of each node is set inversely proportional to the number of neighbors it observes at a given moment. Also, this probability is chosen to match a good tradeoff between the number of retransmissions and the reliability, according to a formal analysis. The counter based phase can be viewed as a corrective measure that helps in boosting the reliability to much higher numbers. Finally, the lazy gossip kicks in whenever even the counter based corrective measure fails to deliver some messages.

The majority of the messages is received by probabilistic forwarding and only a small portion is received during to the counter based phase or through lazy gossip. Thus, the high latency of the last two measures is only seldom paid. The result is a protocol that sends a small number of messages compared to other known alternatives and guarantees high reliability with any topology. The protocol is also computationally very efficient, and it is highly resilient to mobility, failures, and selfishness, due to its probabilistic nature, the reliance on local information only, and the gossip mechanism. In particular, it does not rely on any 2-hop neighborhood information.

4.2 Energy-aware Broadcast

As already stated, devices in MANET and WSN have low capacities in terms of a battery supply and, therefore, reducing battery consumption is a key requirement in these networks. Decreasing battery consumption can be achieved by adapting transmission range or by using a special directional antenna. The second solution requires a special hardware configuration and is thus outside the scope of this report.

Decreasing the transmission power also decreases collisions and interferences in the network which is obviously good. In many other fields like biology or social networks, networks having a long-tail distribution degree have characteristics that speed up the transmission of information or dissemination of viruses. The idea in [12] is to apply a method that generates networks with the same characteristic. The protocol we propose is to select a transmission range using a power-law function, which presents the characteristics to have a long-tail. With this power-law distribution, a lot of nodes will have a low transmission power, while some have a high transmission power. To prevent nodes having a high transmission power from consuming their battery too fast, each time a node needs to send or forward a message, we redefine its transmission power using the power-law function. We have to notice that this protocol introduces unidirectional links in the network.

4.3 Six-shot Broadcast

The Six-shot Broadcast algorithm *(6SB)* [1] is a location-based broadcast algorithm. It assumes that every node in the network has a positioning system such as *GPS*. The particularity of *6SB* resides in the scheme it uses to decide whether or not to forward a given message. This scheme is based on a widespread mechanism that we dub *wait and see*. With this mechanism, when a message m is received, a node initiates a waiting time during which it looks for retransmissions of m. When the waiting time elapses m is forwarded unless the number of retransmissions seen is higher than a predetermined *threshold*. *6SB* assigns a different waiting time depending on the geographical location of nodes. The idea is that before a node sends a message m, it associates six geographical *targets* to it. Then among all nodes that receive m, only those located closest to a target should forward m. Note that only nodes located in what is called the *forward zone* can possibly forward messages, all nodes located in the *no forward zone* never forward a message to avoid that nodes too near of the sender retransmit the message.

6SB is suited for fully decentralized networks with expected connectivity such *MANETs* or *WSN*. This algorithm is not valid for opportunistic networks due to the too frequent partitions of the network. These partitions stop the diffusion of the message.

4.4 Location-based Publish/Subscribe

The location-based publish/subscribe service (LPSS) [10] can be seen as a generalization of the combination of topic-based and content-based publish/subscribe, predominant in industrial-strength solutions for wired settings. The matching in LPSS is performed on the content of events like above, but in addition on a *geographical context* as well. This notion of geographical context is more dynamic than that of a topic, but similarly can be viewed as orthogonal to the content of events.

With this notion of context, an event is typically restricted to a defined range around the publisher, respectively the subscriber. This range defines the publication space, respectively the subscription space. To be called a location match, both subscriber and publisher must be located in the intersection of both spaces. This explicit distinction between content and geographical context is motivated by their difference in nature, the former being static and the latter being highly dynamic.

The loosely decoupled nature and the here and now semantics of LPSS are well suited for mobile networks with expected connection levels such as MANETs, VANETs and WMNs. However, the here and now semantics are not compatible with the long delays and partitions of weekly connected networks such as opportunistic networks.

4.5 Mobility-assisted Publish/Subscribe

There exists in the literature several different solutions for providing a publish/subscribe service in MANETs [7, 2, 17]. However, such solutions perform poorly in mostly disconnected environments like opportunistic networks. As described in Section 2.5 such settings usually do not provide immediate end-to-end links, and communication has to rely on a *carry and forward* dynamic to be able to route events to the intended subscribers.

A possible approach for the implementation of a publish/subscribe service in an opportunistic network setting is to restrain the interaction between nodes to the case where one of the peers is a subscriber to the event being forwarded, and rely solely on the mobility of nodes to promote these useful encounters. This will significantly decrease the costs of communication by reducing the amount of transmissions required to distribute events. On the downside, all nodes in the network must have storage capabilities and be willing to carry a significant amount of information. However, they will only carry events to which they also subscribed, thus promoting a mutual advantage among peers interested in the same topics.

Another approach is to leverage on the mobility and encounter patterns to predict the best candidates to carry the messages, even if they are not subscribers of the same, or any, topic. Costa et. al. [6] propose a publish/subscribe algorithm that applies a forecasting technique that identifies possible future co-locations between nodes and uses this information to select the best carriers. It assumes a socially-inspired mobility model and a correlation between nodes co-location and similarities in the nodes subscription set.

4.6 P2P DHT in Mobile Ad Hoc Networks

P2P overlay networks in the Internet and mobile ad-hoc networks share many key characteristics such as self-organization and decentralization due to the common nature of their distributed components. They also share a high degree of dynamicity as nodes can join and leave the network at any given time. These common characteristics lead to further similarities between the two types of networks: both have a frequently changing topology caused by nodes joining and leaving dynamically. Also in MANETs terminals are mobile and communication follows a hop-by-hop connection establishment.

Wireless multi-hop networks, such as MANETs, feature several peculiar aspects which significantly differentiate them from other wireless systems and pose serious technical challenges, especially when P2P applications are targeted. Examples of such challenges are the characteristic of wireless multi-hop transmission (e.g. hidden terminal), the mobility of nodes, P2P overlay maintenance, network resiliency, routing stretch, and node heterogeneity [13].

Deploying a DHT directly on top of an existing broadcast based ad-hoc routing protocol does not require any changes to the routing or overlay layer. Every file name and peer is hashed to a key by standard hash algorithms (e.g. SHA-1). Every peer should maintain a small routing table of size $O(logN)$, in which each entry directs to an intermediate peer closer to the requested key. The peer closest to the requested key knows the address of the actual peer storing the requested file. In order to route to these intermediate peers, standard MANET routing protocols are deployed which usually acquire topology information using broadcast. However, in order to maintain the correctness of each overlay routing table, peers need to periodically communicate with each other through overlay management protocols. These protocols should be triggered more frequently in MANETs due to mobility and characteristics of the underlying physical networks, otherwise routing information at the overlay might not be consistent. The comparison carried by [5] tries to find a balance between lookup efficiency and management traffic overhead. Too frequent management traffic leads to high overhead in multi-hop environments and thus leads to network congestion.

No management, on the other hand, will lead to low lookup efficiency.

In particular, the DHT paradigm with its notion of regular topology (often a ring) and the shortcuts (fingers) introduced at the overlay layer makes a direct mapping to ad-hoc networks difficult. An optimized interaction between ad-hoc network and DHT is essential to create an efficient combination. For example, Scalable Source Routing protocol (SSR) [11] integrates the P2P overlay into the network layer by combining the Dynamic Source Routing protocol (DSR) [14] in the physical network with Chord routing in the virtual ring formed by the address space. Fuhrmann states that SSR trades off shortest path for a reduced amount of state information, leading to less maintenance overhead. Following the DSR concept, data packets of SSR contain a source address, a destination address and a source route. By constructing the route cache, each node contains source routes to the node's neighbors in the virtual ring. Beside that, the caches will contain source routes to other destinations also. For example, all nodes that are part of a source route in the cache can be viewed as potential destinations. When routing a packet, the respective node chooses the (intermediate) destination from its cache that is physically closest to itself and virtually closest to the final destination of the packet.

To maintain the virtual ring consistency in SSR, all nodes must have valid source routes to their respective virtual neighbors; e.g. its predecessor and successor in the address ring. The nodes need also to have information about their physical neighborhood, information which is gathered through a periodic beacon message (e.g. hello message). The state maintenance of the virtual ring continues until all nodes have mutually correct virtual neighbors, in order to guarantee network convergence. To reduce the routing stretch, SSR's nodes use the source routes in their routing caches to prune unnecessarily long source routes, e.g. routes contain cycles or a shorter sub-path to one of the nodes in the source route is known (short cut).

Besides SSR, there are several approaches ([15, 4, 8, 18, 3]) proposed in the literature that also try to exploit similarities between ad-hoc network and DHT in order to integrate them in a system with higher performance, by also reducing the overheads.

4.7 Multicast Trees

As MANET's resources are limited and the network topology often changes; it is important that an adapted multicast algorithm avoids unnecessary expensive communications and maintains an efficient tree structure in this changing environment.

The multicast tree building algorithm presented in [16] builds and maintains a source based multicast tree on top of MANETs. The source node is responsible for the multicast group and is the root of the multicast tree. To deliver data to the group members, a provider has to send data to the source which will forward it to the multicast tree.

The multicast tree building algorithm works upon a Distributed Hash Table (DHT) specifically designed for MANETs [15]. Thus, a content provider requests the DHT with the groupID as key to distribute data throughout the multicast tree. Then, the DHT substrate efficiently routes the request (i.e., the data) toward to multicast tree source.

In the same way, to join a multicast tree; a node requests the underlying DHT with the desired groupID as key. The DHT algorithm then routes the connection request toward the source. All the nodes receiving the request along the path to the source (by forwarding or listening it) can propose themselves as parent, but at least the source will answer. Thus a connecting node potentially receives multiple connection proposals and can choose a parent physically close in order to limit the communication cost. As a node is responsible for its children, the membership management and its load is distributed among all the participating nodes. This approach offers better scalability than centralized membership management, especially in MANETs.

Once connected, the member nodes use the group multicast messages (i.e., received, forwarded and passively listened) distributed among the tree to imagine the local physical topology. The Nodes can change of parent if the new configuration better fits to the actual physical topology and doesn't disconnect the tree.

Experimental evaluation of the multicast tree building algorithm has shown that it builds and maintains trees where nodes physically close from each others are connected together. As they are separated by only few physical steps in the mobile environment, the communication and route maintenance cost are limited. Moreover, the distribution load is shared among the participating nodes thanks to the distributed membership management.

This distributed membership management and operation mode where only local information are available achieve good performances in ad-hoc networks like MANETs and mesh networks, with good scalability. On the other hand, as such algorithms build and maintain connected trees among the participating nodes; it doesn't fit with opportunistic networks where the network may be often partitioned for an undetermined amount of time. The disconnected nature of those networks not only partitions the trees but also may prevent a connecting node from finding a member node or the source to join the tree.

5 Conclusion

Devising adequate protocols for mobile networks is a strenuous task. Same protocol cannot be devised to target all mobile networks. Protocols implementation must be tailored to each category of such networks and address their specific issues. Since many protocols target one kind of network there is a room for future investigations.

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