Building resource aware middleware services over MANET for rescue and emergency applications

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***Abstract*— In the Ad-Hoc InfoWare project we investigate middleware solutions for mobile ad-hoc networks (MANETs) used in emergency and rescue situations. One goal in the project is to increase availability of services and information through resource awareness. In this context we regard the ability to predict with a certain confidence the future resource availability as very helpful. The work described in this paper, presents our current progress towards prediction of future connectivity between nodes using information about a node's neighborhood extracted from the routing protocol. The simple idea is that if two nodes have been close to each other for a certain time, there is a high probability that they will be close also in the immediate future. The advantage with our approach is that the nodes do not need location information. We are using simulation to analyze for how far into the future we can make valid predictions.**

I. Introduction

Efficient collaboration between rescue personnel from various organizations is a mission critical key element for a successful operation in emergency and rescue situations. There are two central preconditions for efficient collaboration, (1) the incentive to collaborate, which is naturally given for rescue personnel, and (2) the ability to efficiently communicate and share information. Mobile ad-hoc networks (MANETs) have the potential to provide a "best effort" network infrastructure for information sharing in such scenarios. MANETs are typically highly dynamic networks in terms of available communication partners, available network resources, connectivity, etc. Furthermore, the end-user devices are very heterogeneous, ranging from high-end laptops to low-end PDAs and mobile phones. CPU storage space, bandwidth, and battery power represent important resources. Finally, many application scenarios, like coordination of rescue teams, have also quite hard non-functional requirements such as availability, efficient resource utilization, security, and privacy. Both the heterogeneity of devices and the broad range of functional and non-functional requirements, impose the need for resource management mechanisms. Because of the dynamic nature of MANETs, middleware for resource sharing based on traditional resource reservation will not work in a proper manner, and guarantees for resource availability cannot be given. Instead, best effort resource reservation might be treated as a soft-state which is only valid for a specified time, either for the time period the resources are needed exclusively by a process, or for the time period the resources are (with high probability) accessible. Resource management can benefit from predicting future availability of resources, not only to establish meaningful time-outs for soft-state reservations, but also to increase the availability of information and services through replication and graceful degradation. There are several approaches to address prediction of future connectivity and by this, future access to resources and services. One approach is to analyze location and movement of nodes with GPS information. However, GPS devices might not always work, e.g., in buildings and tunnels.

Another approach might be to use application layer knowledge about roles of persons and group memberships. However, this kind of information might not always be available. Therefore, we perform in this paper a kind of worst case study, i.e., no location information and no role and group membership information is available. The simple idea to address such a worst case situation is that if two nodes have been close to each other for a certain time, there is a high probability that they will be close also in the immediate future. For example, two devices that are carried by the same person or vehicle, or devices that are carried by members of the same team which work close to each other.

This work-in-progress paper presents our current progress towards achieving resource availability prediction by using such neighborhood history information, which we extract from the routing protocol tables. We are using simulation to analyze how useful history information on neighborhood relations is to predict future neighborhood relations, and for how far into the future we can make valid predictions. The remainder of this paper is organized as follows. In Section II, we present our rescue scenario and challenges for a resource manager in MANETs. In Section III, we give an overview of related work. Our initial design of the resource manager and its subcomponents are presented in Section IV. We introduce our first experiments in Section V, and give some conclusions and outlook to future work in Section VI.

II. Rescue Scenario and Challenges for Resource Management

In order to illustrate the characteristics of MANETs used for rescue scenarios and the application requirements, we use as an example a national rescue exercise where several hundred persons need to be rescued due to a train accident in a tunnel. In this rescue operation, many teams from different organizations participate and cooperate. The diversity of the teams involved and their specialized devices introduce a heterogeneity of devices and configurations on the scene. The

devices can range from streaming servers to sensors reading the temperature, so many of them have limited resources. They are all potential sources of information, but information becomes stale very fast. Specific to the rescue scenario is that personnel is often traveling and acting in teams, and that team members are inclined to cooperate. Team members can however leave the vicinity of their colleagues at any time when a situation unknown to the middleware demands it.

We call devices that are capable of becoming part of a MANET *nodes*. We distinguish *mobile nodes* that change their physical position with respect to the other nodes, and *stationary nodes* that move insignificantly after their deployment. At the best some of the nodes in the network are aware of their own location, for example through the Global Positioning System (GPS). These nodes can then provide their position as service information. This type of service will however not always be available, because GPS devices will not always work, e.g., in tunnels. It is reasonable to believe that many nodes have important data for other nodes, like temperature measurements of the air in different regions of the tunnel.

We use the term *resource* to denote both physical resources (such as CPU cycles, memory, storage and bandwidth) and software registered as resources (such as image format converters and media players). Specific for our scenario are the key assumptions that most of the nodes have various resources they are willing to share and they provide services to each other. In the worst case, the nodes collaborate only by sharing bandwidth and providing routing. In the ideal case, nodes share resources in such a manner that storage of information and computation becomes pervasive. Nodes may experience communication failure for reasons such as physical obstacles, wireless interferences, power down, network partition, and routing protocol failure.

In this paper, we investigate resource management for MANETs where nodes have a strong incentive to collaborate and share resources. The frequent communication disruptions make a centralized or semi-centralized approach unusable, and most of the devices cannot determine their exact position all the time. Our identified challenges include a need to provide support for graceful degradation and replication of data and computation to running services. This requires finding suitable resources, and it is also necessary to find ways to balance the lack of resources on nodes, all the while preventing data loss. The requirements lead us to the architecture presented in Section IV.

III. Related Work

Most of the existing work on resource management in ad-hoc networks is oriented toward studies of QoS (Quality of Service) [1], [2], [3], [4], bandwidth management [5], [6] and mobility management [7].

Some of the existing work proposes the use of node mobility information to improve information accessibility in MANETs. For example, Chen et al. [8] propose a framework for a distributed data accessibility service to access multimedia data within a heterogeneous cooperative group. It is assisted by a predictive location-based routing protocol which tries to maintain a specific set of QoS parameters. For this they assume that nodes move in groups and follow predictable movement patterns. Each node constructs movement patterns of its neighboring nodes, relying on information like the geographic location of nodes, movement direction and velocity, transmission range of the node, and on received periodic positions broadcasted from the nodes. Using movement patterns, each node participating in a transmission is capable of predicting the future location of the intermediate nodes and destination. Under similar assumptions, NonStop [9] constructs the movement patterns for a set of mobile nodes which exhibit similar mobility patterns in their movements. They are used to guarantee the continuous availability of multimedia streaming. NonStop estimates the occurrence of network partitioning to replicate data to a streaming server that has a low probability of being disconnected from a requesting client during a streaming session.

Routing protocols for applications that tolerate a high degree of asynchrony in message delivery are proposed in [10], [11]. These solutions choose the next hop for a message with the help of a utility function to get the message close to the destination. The utility function uses data about recently and most frequently noticed hosts, and combines it with Kalman filter theory in [11] and application layer knowledge in [10].

The network MAC layer can also provide useful information. For example, Hu and Johnson [12] propose a solution based on the use of congestion information to avoid network hotspots by locally monitoring the network interface transmission queue length and MAC layer behavior at each node. For optimization, MARE [13] tries to reduce bandwidth requirements by moving operations rather than transmitting data across a network. Information on available resources (services) is shared by periodically announcing availability of resources through distributed tuple spaces. Allia [14] uses peer-to-peer caching and policy-driven agents to facilitate cross-platform service discovery. In terms of replication strategies for MANETs, relevant work includes strategies proposed by Hara [15]. The emphasis is put on access frequency and network topology, and the proposed strategies consider also the periodic update of replicated data. AdHocFS [16] is a distributed file system based on collaborative caching among ad hoc groups of trusted terminals in direct communication range of each other.

Although research in this area has been performed, the existing systems cannot be used directly in our scenario. For example, [8], [9] assume that every node has a means of determining its position, which does not apply in our case. Additionally, in our scenario nodes have heterogeneous capabilities, and it is reasonable to believe that not all of them have the ability to predict partitions or to participate in replications. Although [11] uses Kalman particle filters to predict future connectivity of nodes, these filters do not usually have the capability of capturing the non-Gaussianity, high dimensionality and nonlinearity elements of real life data. However, the existing mechanisms have interesting properties

which we use also in our system: data replication based on predictable movement patterns and mechanisms that can predict group partitioning [15], and exploiting MAC layer information to derive useful information regarding user proximities [12]. As an improvement, our system shares information about more diverse resources than merely bandwidth [13]. We consider controlling the dissemination of resource information as proposed in [14].

IV. Architecture

In this section we describe our initial design of the Resource Manager (RM) and how its sub-components are supposed to address the identified requirements. The other components of the Ad-Hoc InfoWare middleware and their interfaces with the RM are described in [17].

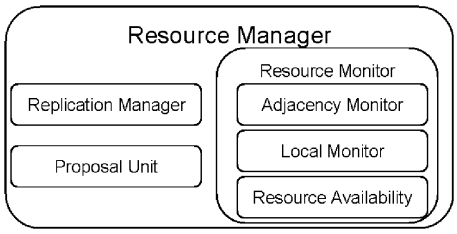


Fig. 1. Resource Manager components

A. Resource Manager Components

The two main tasks of the RM are resource monitoring and resource information management. Resource monitoring is built on three components (see Figure 1):

- *Local Monitor*: The Local Monitor monitors the status of all resources on the node.
- *Adjacency Monitor*: Remote resources are monitored by the Adjacency Monitor, which is also responsible for monitoring the characteristics of the network connections and the identities of the current neighboring nodes (in direct communication range).
- *Resource Availability*: Distribution and dissemination of resource information are handled by the Resource Availability. It has two possible behaviors: proactive, represented by searching information about available resources, and reactive, represented by disseminating information about available resources at request.

The RM can be configured such that it adapts to the available resources on the devices it is supposed to run on; the minimal configuration should contain just the Local Monitor and the Adjacency Monitor. Nodes that are able and willing to contribute their resources to others in the network, and nodes that want to use such resources, must also implement the Resource Availability. Resource users must in addition implement the two components that are used to manage and apply the data that is collected by the monitoring components, i.e.,

- *Proposal Unit*: The main task of the Proposal Unit is to predict future availability of resources and services, including possible network partitioning. Based on these predictions, it proposes how to optimally make use of resources on other nodes. It uses local and remote resource information, group membership descriptions, and any other high-level information available.
- *Replication Manager*: The Replication Manager handles replications of data and computation for the local node. It uses the Proposal Unit to get recommendations about when to use respectively to free resources, where to replicate data, and which resources to use on what node.

B. Prediction of Resource Availability

In this section, we introduce the ideas behind the Proposal Unit. To predict availability of resources, the Proposal Unit first predicts the future connectivity of the nodes. The second step is to gather information about available resources on other nodes. The third step is to disseminate the resource availability information in the network. To determine the connectivity to nodes it is useful to estimate their current and future position. A way to perform this, is to determine the mobility patterns for a node and group of nodes. One constraint in our application domain is that it is not possible to have exact location information on all nodes all the time. Therefore, we focus in this paper on a solution that works without such information. In particular, we study how to utilize already existing information that is managed by the routing protocol and stored in the routing tables, because such a solution will not introduce additional network load, e.g., through beacons. Our solution should be independent of the routing protocol and should work well with proactive and reactive protocols. Additional information, like wireless bandwidth characteristics, statistics of adjacency of nodes, or group membership description might also be helpful, but their usage is out of the scope of this paper and subject to future work.

Here we describe and analyze a solution for a worst case scenario, i.e., nodes move in a random manner and the routing protocol is reactive. The solution is based on building histories of neighborhood nodes from information about nodes in direct communication range. Depending on the particular routing protocol, nodes in one hop distance are explicitly identified in the routing table. For example, the Ad Hoc On-Demand Distance Vector (AODV) routing protocol [18] identifies these nodes as neighbors, and it provides additional mechanisms to keep an updated look over the nodes' current neighbors. The choice of AODV was made based on the fact that it is one of the most widespread protocols, and its reactive nature brings a new dimension to the worst case scenario we want to study.

AODV is a reactive routing protocol, meaning that it discovers the routes on an as-needed basis. It maintains a route for as long as it is used, i.e. to transmit and receive data. The routes are loop-free since it uses a solution based on sequence numbers on nodes and communication groups. It can be used only in networks with symmetric links, since a destination node will reverse the path to get to the source node. One of the advantages of AODV is that it supports a concept of neighborhood, by keeping track of nodes in one

hop communication range. A node may offer connectivity information by broadcasting local hello messages as long as it is part of an active route. It may determine connectivity to nodes by listening for packets from its set of neighbors and by consulting the routing table. A node can use these data to build histories of connectivity to other nodes, by storing information about the times when a node was in direct communication range. Our hypothesis is that such connectivity or neighborhood histories are a good basis for predicting the future connectivity. In this context, one important question is how "good" such predictions are, i.e., what is the statistical confidence in certain predictions, and for which periods of time are we able to make meaningful predictions.

V. Experiments

The simulations were performed in the Global Mobile Information System Simulation Library (GloMoSim) [19]. We have extended GloMoSim (with the assumption of the standard distribution) to use node speed specified in the mobility trace files and upgraded the AODV implementation to version 13 implementing the RFC 3561 [18]. Additionally, AODV was extended to log all the nodes in one hop communication range. In order to build and analyze the connectivity history, we extract the connection periods of time between two nodes, meaning the periods of time when a node reports another node as its neighbor. These connection periods of time create the list of connections. Similarly, we create a disconnection times list, the list with periods of time when a node does not report another node as its neighbor. We use these lists with periods of time to analyze the variance of connection and disconnections between nodes over the duration of the simulation. This analysis gives us a good indication on the estimation period we can use when attempting prediction of nodes connectivity.

We have chosen the *Steady-State Random Waypoint Mobility Model* [20] mobility model for our initial study, because it is a derivate of the *Random Waypoint Mobility Model* (one of the most used mobility models). In this model the initial locations and speeds of the nodes are chosen from the stationary distribution, convergence is immediate, as such no data need be discarded, and the simulation results are reliable.

The network consists of 50 nodes spread randomly in a square scene of side 1000 meters. The transition radius of a node is set to R = 250 meters. A node moves at variable speeds in the interval from 4 to 8 m/s. It stops for periods of time between 110 and 130 seconds. The network has only one source of communication, which every 60 seconds transmits an item of size 1460 bytes to all the other nodes in the simulation. The simulation has a time length of 7200 seconds.

As mentioned, we extract from each node a history of time intervals for neighboring nodes. We use it to analyze the variance of node connections and disconnections for the duration of the simulation. In Table I we show the minimum, maximum, mean, median, the 1st and the 3rd quartile of the connection and disconnection lists.

Source	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
MB-con	0	34	66	86	115	618
MB-dis	7	177	339	443	5860	2910
AODV-con	20	64	110	172	229	1010
AODV-dis	25	189	250	307	370	1691

TABLE I
SUMMARY FOR THE CONNECTION AND DISCONNECTION PERIODS OF TIME

In Figure 2 and Figure 3, we present the probability density of the connection and disconnection periods using the binned kernel density estimate. We compare the periods that result directly from the mobility model with those a process perceives by inspecting the AODV routing table.

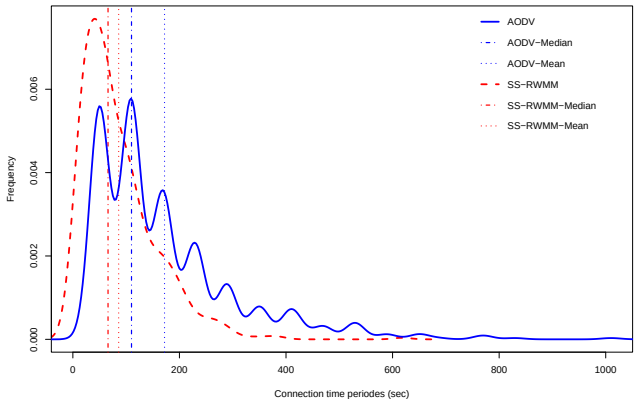


Fig. 2. The probability density function for connection periods from AODV using Steady-State Random Waypoint Mobility Model

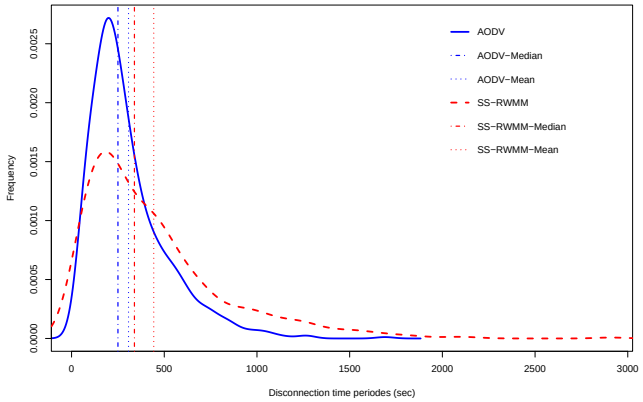


Fig. 3. The probability density function for disconnection periods from AODV using Steady-State Random Waypoint Mobility Model

We observe that the connection periods are significant larger for AODV than for the standard mobility model, whereas the disconnection periods are significant smaller for AODV than for the mobility model. Most of the differences are generated by the settings of the route and neighbor timeouts in AODV. These results give us a reason to believe that the results

obtained trough routing table inspection, reflect well enough the reality, i.e., connectivity and disconnection between nodes reported by the mobility model. As shown in our experiments, in a network with nodes with high mobility, we will be able to make predictions for an interval of 172 seconds.

We conclude that the distributions are close enough to further investigate the presented approach.

VI. Conclusions

In this paper we have described our ideas and architecture for resource management in MANETs for emergency and rescue situations. Furthermore, we have presented our first experiments towards prediction of future connectivity between nodes without location awareness information on nodes. Since the initial worst case studies with the reactive AODV routing protocol indicate that predictions can be made, we conclude that it should work at least as good with other routing protocols.

The presented approach has the advantage that it does not create extra load on the system, since it is not sending any messages but only monitors the routing tables for changes. However, for reactive protocols there is one drawback because they update their routing tables only if they are actively involved in communication. Therefore, the history of neighbors that is retrieved from reactive routing tables on nodes that do not communicate, is not reflecting very well the reality. However, if a node is not involved in any kind of communication, it probably has no neighbors or is currently probably not interested in using resources from other nodes, and neither are other nodes interested in using the resources of the node.

We intend to verify the experiments presented in Section V by repeating them with other routing protocols and to compare the results with the ones from AODV. Also, we want to compare them with experiments where we use non-random group mobility models, e.g., based on social networks [21]. A second step is to perform some regression to estimate the time a node will remain a neighbor.

Acknowledgment

This research was funded by the Norwegian Research Council in the IKT-2010 Program, Project No. 152929/431. The authors would like to thank the Toilers Group at the Colorado School of Mines, USA, for allowing us to use their mobility models implementation, and also the anonymous reviewers for their insightful and helpful comments.

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