Adaptive Context Mediation in Dynamic and Large Scale Vehicular Networks using Relevance Backpropagation

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ABSTRACT

Adaptive context mediation in large scale vehicle networks leads towards *telematics* which refers to the concept of vehicles equipped with context-aware embedded smart computing devices with communication capabilities over certain networks. With the use of telematics we can make use of wide range of smart inter-vehicle communication applications like emergency message transmission, collision avoidance, congestion monitoring and intelligent parking space locator. In this paper we present certain requirements for adaptive context-aware information mediation in large scale vehicle networks. We make use of quality attributes for context information and network properties of large scale vehicle networks and experiment with real time data collected using a car simulator. We simulate *flooding* and other *dissemination* based communication techniques with relevance backpropagation for large scale vehicle networks using OMNET++ to analyze the flow of context information. Our simulation results show that our context-aware and adaptive directed diffusion of information using relevance backpropagation increases the performance of the nodes in a large scale vehicle network with less communication overhead.

Categories and Subject Descriptors

H.3.3 [**Information Storage and Retrieval**]: Information Search and Retrieval—*information filtering, selection process.*; H.3.5 [**Information Storage and Retrieval**]: Online Information Services—*data sharing.*

General Terms

Performance, Experimentation.

Keywords

Vehicular networks, large-scale, adaptation, context-awareness.

1. INTRODUCTION

Inter-Vehicle communication through WiFi and 3G internet access and sensor network technologies are becoming increasingly ubiquitous and a promising field in research. In the ubiquitous computing paradigm, all the objects like vehicles and mobile devices are able to interact with the humans impeccably. Such interactions need the applications to be context-aware towards the sensitivity and the dynamic nature of the environment leading us towards the concept of intelligent transportation systems [1, 9, 6].

Adaptive context mediation in large scale vehicle networks leads towards many application areas like emergency message transmission, collision avoidance, congestion monitoring and intelligent parking space locator. The idea is related to the vehicles being able to acquire relevant context information from the context providers and subsequently manipulate this information to perform context-sensitive tasks [5]. So the idea can be simplified in a phrase i.e. *the right information at the right place and time.* For example, a vehicle searching for parking space at a particular location should get notified about the parking space available closest to the destination at most 200m away from the spot.

In earlier days the cellular or traditional wired networks were used to communicate about a traffic incident to the authorities which was relatively inefficient due to human dependency. Today most of the vehicle manufacturers want to improve this dependency by installing embedded devices with communication capabilities in the cars to support the context-aware applications mentioned earlier. This includes the use of communication networks like WiFi and 3G wireless and sensor networks.

In one of the previous works by the authors [12] it was observed that simple use of GPS tend to make the driver less attentive towards the driving and the road traffic signs. In this paper, we will identify various important context and network characteristics required for effective communication in vehicles by adaptive context mediation in large scale vehicle networks. In a large scale vehicle network the vehicles can be considered as dynamic and mobile nodes acting as smart objects sending and receiving context information to other smart objects. The *flooding* and *dissemination* techniques will be used for communication between vehicles or smart objects in our simulated experiments using OM-

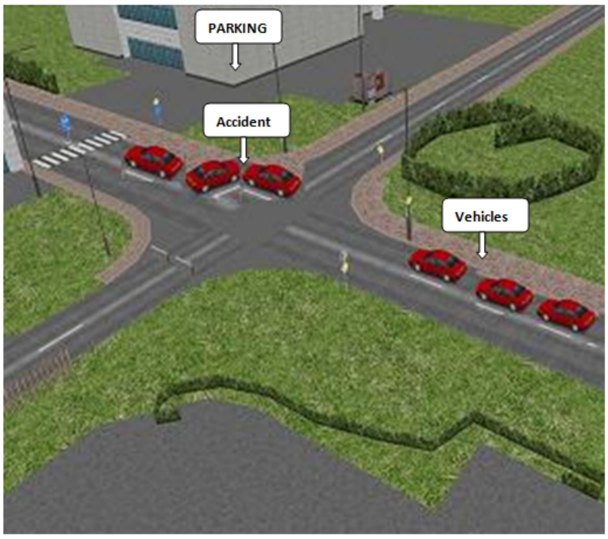

Figure 1: Traffic accident on the road near the parking spot.

NET++. In the *flooding* technique every smart object and vehicle broadcasts the information to everyone, whereas in the *dissemination* technique the information is only broadcasted to a limited set of smart objects and vehicles. *Flooding* is not a scalable solution due to the large number of messages flooding over the network and *dissemination* on the other hand is a scalable solution due to the limited number of message transmission over the network according to the authors [9]. Like in Figure 1 the emergency message related to the accident should only be broadcasted to the vehicles moving towards the direction of the accident. We also present a comparison between the different techniques proposed by others [9, 4, 3] with this mechanism to shows its effectiveness. We also propose a set of requirements to be taken into account while dealing with the large scale vehicle networks. The issue concerning the use of a specific network is not dealt with in this paper as it has already been discussed by various authors [8] earlier in this domain.

In section 2, we present some motivating scenarios and case studies. Requirements for adaptive context mediation in large scale vehicle networks are discussed in section 3. In section 4, we describe some context and network quality properties of large scale vehicle networks. In section 5, the communication techniques for large scale vehicle networks are described. We present our simulated experimentation work on the simulator with analysis and results in section 6. Related work is discussed in section 7. The conclusion and the future work is presented in section 8.

2. MOTIVATING SCENARIOS AND CASE STUDIES

The term 'Sacalability' has often been an important but a difficult aspect to address. 'Large scalability' can refer to to the (i) large number of participants or (ii) large number of interactions in terms of message passing between the participants or (iii) lage area of interaction. We refer to it by covering both the aspects of the large number of vehicles and the large number of messages being passed. In order to further extend and explain the concept we present two scenarios related to the deployment of emergency response teams and emergency messages dissemination and intelligent parking space information transmission to vehicles.

We are dealing with a large scale vehicle network in the scenarios involving different kinds of mobile and sensor networks. As it is very likely that there are other embedded devices like PDA's, cellular phones, laptops, etc present along with the vehicle's GPS network, we can also make use of these networks for better performance.

2.1 Deployment of emergency response teams and emergency message dissemination to vehicles in a traffic incident

Deployment of Emergency Response Teams to a traffic incident has always been a crucial point with authorities. Traditionally in case of an incident information is sent to the concerned authorities about the type, location and time of incident over the cellular or wired telephone networks and there might be a road traffic jam at the same place. The problem with the current system is that the cars are often informed too late and the message itself is usually broadcasted to all the vehicles, also to those that are not in the neighborhood of the accident. Let us consider a scenario where an accident occurs between two vehicles travelling from Leuven to Brussels on the highway E40 causing a traffic jam. A vehicle owner on the same side of the road informs the emergency response teams using his cellular phone after the incident has occurred. The emergency response teams arrive on the location after 10mins to rescue the victims and to put up a sign informing about the incident 500m away to inform the upcoming cars so that they can change their routes to avoid a traffic jam. But within this time frame quite a large number of vehicles are blocked on the road due to the accident which might take time to clear up in a few hours. We discuss the solution through adaptive context mediation in detail later in this paper.

2.2 Intelligent Parking Space Information Dissemination to Vehicles in a Metropolitan city

Nowadays, most of the new vehicles have an embedded Global Positioning System (GPS) device to assist the drivers while driving from one location to another. Let us take a typical case of Brussels city during the rush hours when there are thousands of vehicles on the roads. Brussels is one of the most popular cities in Europe and a tourist attraction as well. Several of these vehicles are in search for a parking space near to their destination. The parking spaces are badly managed and are not intelligently used for providing parking information to the vehicles. Even the installed GPS is of no use in this situation. Traditionally the parking information is displayed on electronic boards within the city for different parking spots. In some cases when a particular vehicle finds a vacant parking space and reaches that parking space it is usually occupied by another vehicle as the information about free parking space was either too old or the information changed on the electronic board as soon as the vehicle passed by it. So in most of the cases either the vehicles park too far away from their destinations or waste a huge amount of time in search for a nearby parking space. An intelligent solution is provided through adaptive context mediation later discussed in the paper with reference to the scenario.

3. REQUIREMENTS FOR ADAPTIVE CONTEXT MEDIATION IN LARGE SCALE VEHICLE NETWORKS

In this section we list certain requirements for adaptive context mediation in large scale vehicle networks with reference to the motivating scenarios described in the previous section. In our analysis we discovered four major requirements:

1. **Mobility-awareness:** Mobility-awareness is a broad term involving few very important aspects required for adaptive context mediation which are *efficient routing with spatial coverage*, *location-awareness*, *velocity of the object* and the *direction of the object.*
   - *Spatial coverage* deals with the geographic area in which the context information is relevant. So the application must not only be able to identify the geographic coverage area, but also *efficiently route* the context information. Although spatial coverage is a fixed variable inside the application, the application should be able to adapt the efficient way of routing based on the context information. For example, if in scenario 2.1 the accident has occurred on a particular side of the road, the context messages are only relevant for the vehicles traveling on the same side of the road towards the accident. So the geographic coverage area in this case will be the region of let's say 800m on the same side of the road where the accident has occurred and the accident information should be routed within this area.
   - We take the same scenario to explain *location-awareness* as the emergency response teams are interested in the exact location of the accident to work efficiently. So the application must be able to adapt the location information and react on it accordingly upon arrival of new context information.
   - *Velocity* and *Direction* are also important for the aspect of mobility-awareness. Such information about an object should also be handled by the context-aware application dealing with large scale vehicle networks. For example, whenever the velocity information is zero for a couple of vehicles it depicts that there is a traffic jam.
2. **Timeliness of information:** Arrival of on time information has always been a challenge for the application developers for adaptive context mediation. It is crucial that only up-to-date context information reaches its destination as the information might not be relevant after a certain period of time. The duration of the relevance can be provided by the application. Referring back to scenario 2.2 assume that the context information about free parking spot is to be retransmitted every 5 mins to every vehicle within the area of spatial coverage. When the vehicles looking for a parking spot do not receive the same message for free parking spot for 10 mins then they should consider that free parking spot is occupied by another vehicle. Also a message more than 5 mins old should not be forwarded.
3. **Signal-to-Noise Ratio of the context information:** *Signal-to-Noise ratio of the context information* is another interesting factor dealing with the relevant context information being received by a smart object over the context information being transmitted by a context provider. The context signal is the amount of relevant information for the node itself, whereas the context noise is the amount of relevant information which the node will forward to others but irrelevant for itself. The higher the signal-to-noise ratio the better it is as less relevant context information is dropped while transmission over a large scale network. As we are dealing with a large scale network of vehicles and such a network is highly mobile in nature so the degree of signal-to-noise ratio is of high importance.

4. CONTEXT AND NETWORK PROPERTIES OF LARGE SCALE VEHICLE NETWORK

In this section we identify several quality properties for the context-awareness and the network being used. These properties will be useful for the designers to build applications specific to the vehicular network with much ease and comfort.

4.1 Generic context quality properties

Intensive research [11, 7] has already been conducted in order to identify the quality properties. In the earlier research by the authors [10] several context quality properties have been identified to resolve the ambiguity of the context information. The ambiguity might arise due to the heterogeneity of the network. We will use some of the current quality properties relevant for the large scale vehicle networks:

1. **Location:** This property refers to the location and other related properties of the information source and those of its targets. This information is used to disseminate context to relevant mobile nodes e.g. the information for the cars traveling from Leuven to Brussels might not be relevant for the cars traveling from Brussels to Leuven. This concept does not relate to the network coverage. A smart object in a certain area covered by a network may be outside the relevant region or vice versa.
2. **Time:** Some applications may be interested in historic values of certain context. Therefore, we keep track of when the information was generated by the context provider and when it was passed along at each node until it arrives at its final destination. As the context provider also specifies the duration of the relevance each node along the path can decide to no longer forward the message when the message has expired.
3. **Semantics:** Each node in the network must be able to decide whether the information it was passed along is

relevant for its purposes or not. Therefore, the context provider specifies the semantics of the context information so that each node can interpret it correctly.

4. **Availability:** Availability refers to the the concept that the smart object is never sure about what information can a context provider can deliver. This context quality property deals with the reliable distribution of the context information to a smart object. Even if relevant context providers are present the smart object may not receive the information due to the dynamic behavior of the network.

These context quality properties can be combined for example the *Semantics of Spatial Coverage* could be defined in terms of a name and geographic coordinates.

4.2 Network quality properties

The network plays a vital role in a large scale environment to process and deliver information from one smart object to another. In this section we will discuss some of the important network properties for a large scale vehicle network:

1. **Throughput:** Throughput is an important factor for information propagation over a large scale dynamic mobile network. It measures the amount of relevant context information being sent over the network by the context provider and compares that with the amount that the context information received by the smart object that subscribed to that information.
2. **Bandwidth:** In large scale and dynamic mobile networks bandwidth usage for context-awareness has always been a matter of concern. Therefore, the context information should be passed between the context provider and the smart objects in an efficient manner.
3. **Time to Live (TTL):** Some of the applications make use of the TTL to decide about the relevance of context information for a particular smart object in the network. If the TTL has expired the information is considered to be no more relevant to be transmitted over the network. TTL also participates in limiting the use of network bandwidth.

5. COMMUNICATION TECHNIQUES FOR LARGE SCALE VEHICLE NETWORKS

In this section we deal with an important aspect of exchanging messages between the smart objects and the context providers in a large scale vehicle network. Context information is either disseminated proactively using broadcast also known as the *push model* – or *on-demand* – also known as the *pull model* – in applications for such a large scale network. In our paper we focus on the *push model* which has a potential of bootstrapping a large scale vehicular network. The aim of the data push model is to exchange context information among a set of moving vehicles on regular intervals. For future work we plan to extend this with a push model for context queries to also handle on demand context dissemination. The pull model can also be implemented using the same techniques as used in the push model. Two main techniques used to achieve this goal are described below:

5.1 Flooding technique for communication

In the *Flooding* technique – also known as the plain *Broadcasting* technique – the context information received by a vehicle is stored locally and then the same information is forwarded using a re-broadcast to others. In a large scale, dynamic and mobile vehicle network flooding may overload the network especially in the case of high traffic volumes thus violating some of the requirements mentioned earlier in section 3. This technique is very useful in the case where the network under consideration is relatively small because efficiently routing the context information to specific smart objects is more expensive in terms of network bandwith and throughput.

5.2 Dissemination technique for communication

Dissemination is another generic technique which intelligently broadcasts the context information only to the interested smart objects. In the case of a large scale vehicle network each time a vehicle receives the context information broadcasted by a context provider it re-broadcasts the context information only to the interested neighbors. The information about the interest of the neighbors is determined by each of the vehicles. The dissemination technique reduces the amounts of context information and does not overload the network, which makes it a scalable solution for transmission of context information over large scale networks. Some types of this kind of dissemination are discussed below:

5.2.1 Types of dissemination techniques

We will briefly discuss about three of the dissemination techniques which can be used in a large scale network.

- **Directed diffusion:** It is the data-centric communication technique widely used for wireless sensor networks. The smart objects like vehicles requests the context information by periodically broadcasting an interest for the named data. Each smart object will create a link with other smart objects or a context provider from which it receives the context information of interest. The link also specifies the data rate and the direction towards which the context information should be sent. Once the link is created between the smart objects and the context provider, the context provider will start sending information of interest to the smart objects probably along multiple paths. As soon as the smart object wants to receive the context information, it will select a specific neighbor from which it will receive the information later on, thus defining a directed broadcast of the context information over a large scale network.
- **Two-Tier data dissemination:** It is a decentralized architecture where a grid structure is used to divide the network into cells. The context providers located at the boundary of the cell need to forward the context information to other cells. The context information is flooded within a cell. One tier is the cell at the smart objects current location and the other one at the cell's boundary. The query is first propagated over the network to create a path between the smart object and the context provider and then the same path is used for

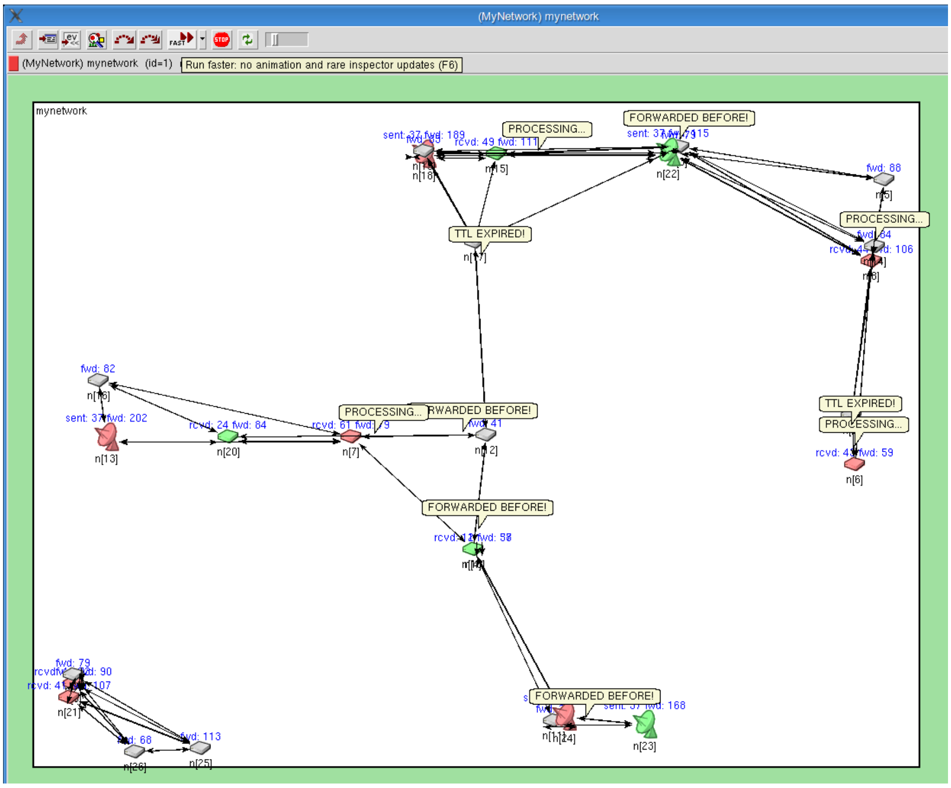

Figure 2: Simulated context dissemination in a network of vehicles.

the propagation of the context information. This technique involves a lot of intelligent routing mechanisms and information storage overhead creating complexities in large scale networks for the application developers.

- **Gradient broadcast:** This technique makes use of a cost variable during the transmission of context information. Initially the context providers set the cost to reach a smart object at infinity. The information is then broadcasted over multiple paths in the network where each of the intermediate context provider or a smart object calculates the cost of receiving the message [3]. At the end each of the context providers or smart objects would have calculated the cost for it to send the context information to a particular smart object. The cost data is later on used to optimally transmit the context information over the network with a minimal cost. This is highly efficient for transmission of context information over a large scale vehicle network but at the same time it creates overhead for each node to calculate the cost information. This could be an issue given the limited processing capabilities of smart objects in large scale vehicle networks.

5.3 Relevance backpropagation

We propose a new mechanism to intelligently disseminate context information to interested smart objects. It relies on feedback of neighboring nodes to reduce the number of peers to forward the information to. The feedback technique is based on context information that decides whether the data that was received is relevant or not. As the context information can be provided by the application itself the routing of the information is adapted accordingly and perhaps different for various applications. We refer to this technique as relevance backpropagation. It is a mechanism to inform the context providers in a large scale dynamic mobile network such as a city wide network of vehicles, about the usage of their information [10]. In this mechanism the goal is to efficiently filter and route the information as close to the source as possible for which some of the technologies like Bloom filters are used [2]. This technique avoids the complexity of creating a two-tier cell architecture as well as the expensive computation to define a cost variable. Our approach relates to directed diffusion but extends it with new mechanisms for adaptive context-aware mediation and feedback loop.

6. SIMULATED EXPERIMENTATION WITH OMNET++

OMNET++ is a discrete event simulation environment. Its primary application area is the simulation of communication networks, but because of its generic and flexible architecture, it has been is successfully used in other areas like the simulation of complex IT systems, queueing networks or hardware architectures as well. It can easily be adapted to simulate other scenarios including large scale, dynamic and mobile networks of vehicles. We have used *Flooding* and *Directed diffusion* techniques with relevance feedback information in our simulated experiments.

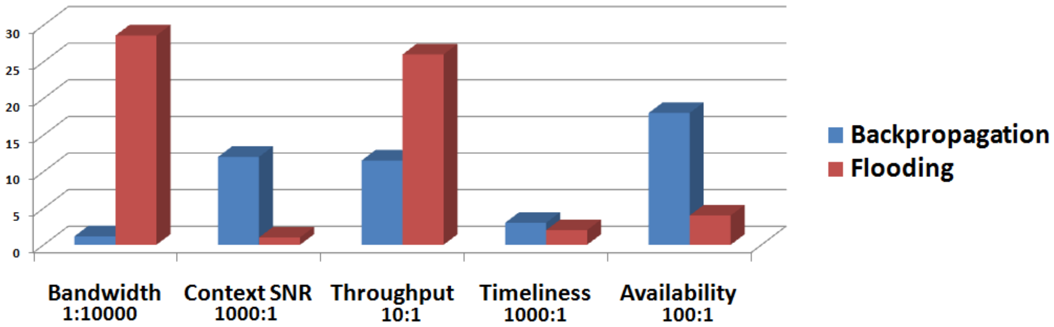

Figure 3: Simulated (rescaled) results using flooding and directed diffusion with relevance backpropagation of information.

6.1 The testbed and experimentation

In our scenario 2.1 and scenario 2.2 the solution we propose is to make use of the adaptive context mediation in large scale vehicle network. This can be achieved by using directed diffusion technique with our relevance backpropagation mechanism in the both the scenarios. In scenario 2.1 the context information alerting them about an incident will only be sent out to the vehicles moving towards the incident happened on a highway by using our mechanism on time and with efficient bandwith usage over a large scale network of vehicles. Similarly in scenario 2.2 the context information regarding the free parking space will also be disseminated only to the vehicles within a region of 500m and moving towards the direction of the free parking space by making use of the relevance backpropagation to achieve adaptive context mediation in large scale vehicle networks.

We have used real time data from a multi-user distributed car simulator [12] collected earlier by the authors. The parameters we have taken into account are (i) time, (ii) velocity, (iii) direction, (iv) x and y coordinates, (v) number of sent packets, (vi) number of received packets, (vii) number of forwarded packets and (viii) time-to-live (TTL) for each node to perform simulated experiments with OMNET++. In the experiment, we let nodes move around like cars and let connections appear and disappear according to the range to other nodes. Several nodes acted as context provides whereas other nodes acted as context receivers. All nodes forward the information to their peers as long as the maximum TTL has not been reached and all context constraints are met. Figure 2 shows a visualization of the experiment with 27 nodes. We carried out the experiment with basic flooding and with our relevance backpropagation mechanism using the same network configuration and simulated for a period of 1 hour of context dissemination. The results for these experiments are explained more in detail below.

6.2 Flooding and directed diffusion with relevance backpropagation

In the experiment using the flooding mechanism the context information was broadcasted in the network to every node. Whereas, in the experiments with our directed dissemination with relevance backpropagation only the relevant context information was sent out only to the interested nodes in the network. The simulated results achieved are shown graphically in Figure 3.

- *Bandwidth* is the sum of all the sent and forwarded messages in the network. It shows a significant difference in bandwidth utilization (a factor 25) for our backpropagation mechanism.
- *Signal-to-Noise ratio of the context information* is calculated by dividing the total amount of received packets by the sum of total packets sent and forwarded by each node. It is also significantly higher in the relevance backpropagation mechanism compared to plain broadcasting. It illustrates that nodes get more relevant information (i.e. the nodes receive less information they are not interested in).
- *Throughput* of the network is the ratio of the total amount of the information requested by the subscribers by the total amount of the information sent over the network by the context providers. The lower throughput can be explained by the fact that messages are only routed where they are relevant, in some cases broadcasting may deliver messages that our approach does not. However this difference does not outweigh the bandwidth utilization.
- *Timeliness* is the ratio of the number of messages dropped because the TTL was expired versus the number of messages forwarded by each of the node in the network. In relevance backpropagation the timeliness of the information is slightly higher than in plain broadcasting, although in absolute values the number of dropped messages was lower for our approach.
- The *availability* parameter is the ratio of the sum of all the forwarded messages versus the number of messages that were received again and already forwarded previously. The availability of the context information is significantly higher in the simulation results when using our relevance backpropagation mechanism in directed diffusion over a large scale network.

7. RELATED WORK

In [9], the authors present a formal model of data dissemination in Vehicle Ad-Hoc networks (VANETs). They measure how the performance of data dissemination is affected by bi-directional lane mobility. Three models of data dissemination are explained and simple broadcasting technique is found to be sufficiently enough in their simulated experiments. In our research, we deal with the directional dissemination of context information.

The authors present an idea about the WiFi-based connectivity and communication between basestations and moving vehicles in [8]. Vehicles mobility cause a gray periods of poor connectivity which according to the authors are caused by variability in the urban radio environment combined with the vehicle traversing areas of poor coverage. We envision that for large scale vehicle network the use of simple WiFi based communication will be impractical.

In [4], the authors address the issue of optimal data dissemination broadcasts to a network of wireless cells in a large mobile network. They propose that there should be a mix of a single broadcast for the entire network along with an individual broadcast for each of the wireless cells. The authors found a significant improvement in the performance of the network using their simulation results. Our approach uses the idea of disseminating the context information only within the area of spatial coverage.

A comparative performance comparison between three data dissemination protocols (i) Directed Diffusion, (ii) Two-Tier Data Dissemination and (iii) Gradient Broadcast for wireless sensor networks is discussed by the authors [3]. In our research, we found that two-tier dissemination and gradient broadcasting over a large scale network are not cost efficient in terms of implementation complexity and processing overhead. So we make use of a combination of directional diffusion and gradient broadcast of context information in a better manner by using spatial coverage and information relevance feedback acting as a cost function in gradient broadcast so that the context information can only be directed to a specific region with minimal cost and effort.

8. CONCLUSION AND FUTURE WORK

In this paper we proposed a mechanism of relevance backpropagation of context information in directed diffusion to achieve the goal of adaptive context mediation in large scale vehicle networks. We have discussed the requirements for adaptive context mediation in large scale networks with some generic quality properties of the context and the network to be used. We also discuss flooding and dissemination based communication techniques for transmitting context information over a large scale network of vehicles. In order to cover these challenging requirements for communication over a large scale vehicle network we implemented the directed diffussion technique with relevance backpropagation and plain broadcasting in simulation environment using OMNET++. The results proved that by using our relevance backpropagation mechanism significant improvements in a large scale network's bandwidth, timeliness, availability and SNR of context information can be achieved with a very minor overhead of throughput.

We are planning to investigate some other network and context properties to get a broader view of the communication mechanisms used earlier for our simulated experiments. For future work into this domain we are planning to further look into the *on-demand* communication technique and compare the results with our current push-model for communication.

After a detail study we might also investigate the same network parameters by inter-connecting a real embedded smart device like a PDA with the simulation environment to analyze the behavior of the real smart devices. Later on this will enable us to see how our relevance backpropagation mechanism can be improved over other large scale networks with real applications.

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