Making Cars a Main ICT Resource in Smart Cities

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Abstract—**As cars are ubiquitous in today's and tomorrow's cities they could play a major role in the communication of the future. In the last years the development of Inter-Vehicle Communication (IVC) took huge steps forward and therefore gives us exactly the tools needed to accomplish this task. We propose an architecture, named Car4ICT, that puts cars into the middle of future ICT systems. In this system users are able to offer and request services; at the same time, members are in charge of discovering the services and routing the data between users. Members are always cars, therefore they are the central part of our architecture. A user can be a human using a smartphone, a machine offering sensor readings, or even a car which offers storage, processing power, or its own sensor readings. We outline the architecture of our system and the different concepts to connect the users and the members. As such services cannot easily be described with known concepts, we outline our way of identifying the services. Additionally, we present some initial proof of concept simulation results that show the immense potential of the system.**

I. INTRODUCTION

We are observing a major trend towards making our cities smarter or even designing new mega cities of tomorrow from scratch. Information and Communication Technology (ICT) plays a critical role in building smart cities [1] and many research activities have been initiated in this area.

The basic building blocks of future smart cities are smart sensing systems and dynamic wireless network infrastructures. They enable or improve applications ranging from environment monitoring to smart grid and energy efficiency to improved mobility and transportation and to survivability in emergency situations. Technological requirements include robust and fault tolerant wireless communication, wide-spread sensing capabilities, and inherently integrated security and privacy measures. Still, even today, operators of infrastructure are struggling to keep up with the increasing data demand, as evidenced by the push towards newer technologies.

We believe that cars will play a major role in such future ICT systems for the smart cities of tomorrow [2]. One of the main reasons is, simply, that cars are ubiquitous. This holds even in critical emergency situations such as after a hurricane or a tsunami disaster [3]. Secondly, recent advances in Inter-Vehicle Communication (IVC) can make driving not only more safe and efficient (and potentially more relaxing) – they also enable a variety of novel applications: Establishing a network of cars enables them to perform actions single cars (or network nodes) are not able to, as we will also highlight in this paper.

Vehicular networking technology has been investigated since more than a decade now, and it is getting mature for first deployments [4]. Solutions range from the use of cellular networks such as UMTS or LTE to using simple WiFi access points or hotspots along the streets and finally to dedicated short range radio solutions for vehicular networks like, e.g., IEEE 802.11p. Standardization of IVC protocols is focusing on these short range communication protocols in particular. One of the driving forces is the U.S. DOT, which plans to make IEEE 802.11p based Dedicated Short-Range Communication (DSRC) systems mandatory for new cars [5]. In Europe, its counterpart (*ETSI ITS-G5*) is planned to be rolled out as soon as cars are equipped with IEEE 802.11p radios. Furthermore, major Japanese automakers have recently announced 760 MHz based vehicle-to-vehicle and vehicle-to-roadside devices as part of an optional package offered in some 2015 model cars in Japan. For example, sensors installed at intersections are able to detect cars and pedestrians. Cars are then able to obtain this information via the Intelligent Transportation System (ITS) band of 760 MHz. Similarly, there are many other communication technologies that could be considered for IVC in future smart cities. This includes visible light communication [6], Bluetooth [7], and millimeter-wave communications superimposed on radar signals [8]. This heterogeneous vehicular networking brings new challenges but also offers great opportunities [9]. It allows us to design applications and networks in a situation-aware and intelligent way. Current proposals to use vehicular networking technologies mainly focus on enhancing the safety and comfort of drivers and other occupants. In these proposals, cars may become gateways for streaming multimedia content or simply providing Internet access to their occupants, or they become an enabler for emergency services.

In this paper, we go one step beyond providing services to cars' occupants and present *Car4ICT*, an architecture for making cars the main ICT resource in smart cities.

We expect cars to play two major roles in our system: First, by driving around they can act (very simply put) as mobile base stations providing access to the services of a powerful vehicular network. This access can be used by a person waiting at the curb side, a smart building that the car just passes by, or sensors deployed in this environment that have information to be uploaded. Secondly, the cars themselves can offer services, as they will be connected to form a network with incredible

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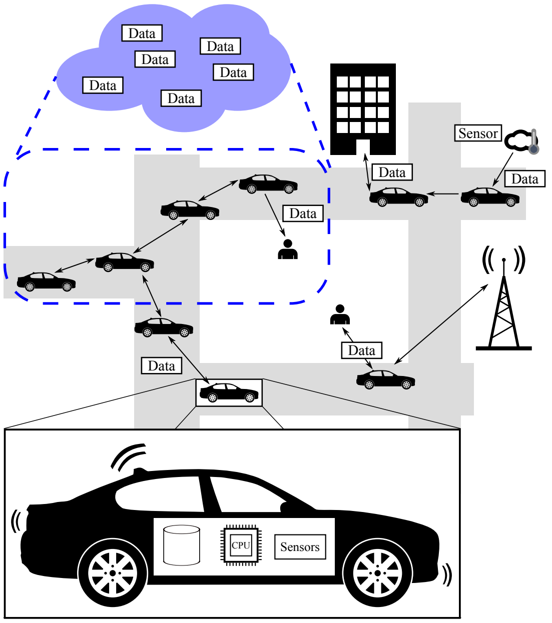

Figure 1. Concept of providing ICT resources in smart cities using mobile and parked vehicles.

processing and storage capacities, as well as sensing capabilities beyond any possible roadside deployment. Such a network formed by cars is different to typical Internet based solutions as it is readily available only in a certain geographical context and during a certain time interval. Parked cars may be used to make both storage and processing capabilities more persistent in time and space. Either way, these networked cars will play a big role in future cities by enabling a multitude of services.

We observe some first activities towards turning vehicles into a larger scale networked system. However, current approaches focus on single, specific applications or require high penetration rates which is a problem in early market introduction or disaster situations. Our Car4ICT architecture is able to support a huge variety of new applications independent of infrastructure.

Figure 1 outlines our concept. As can be seen, users are establishing their connections via the cars in the surroundings. In the top right part a user in a house gathers a sensor reading from a smart sensor along the road, while in the bottom right corner a user connects to the Internet via a car. The left part of the figure shows data stored in multiple cars. It can also be observed that the bottom left car offers various services itself, including storage, processing power and its own radar sensor. Therefore it takes part in the network as a member (discovering services, relaying messages) and – at the same time – as a user (offering services).

In the scope of this paper, our focus is on storage and distributed processing. Yet, the architecture is extensible and flexible, thus, it can be used as a base for many other applications such as distributed sensing. In particular, we are interested in support for environment monitoring, smart grid and energy efficiency, and improved mobility and transportation options – even in emergency or disaster situations.

Our main contributions can be summarized as follows:

- We, for the first time, motivate the use of cars as a main ICT resource in smart cities;
- based on a number of use cases, we detail a network architecture going beyond current information-centric networking systems that supports a variety of applications even in disaster situations when no other infrastructure is available (Section III);
- we present a set of initial performance results outlining the capabilities of our architecture (Section IV).

II. RELATED WORK

Vehicular networking solutions have been investigated since more than a decade now [4]. Main emphasis was given to improving the driving experience. This includes solutions to improve road traffic safety, driving efficiency, and even entertainment solutions. The underlying network protocols and architectures are mostly congestion aware broadcast protocols such as Decentralized Congestion Control (DCC) [10]. Early work on ad hoc routing in vehicular networks demonstrated that routing works only in very local contexts, thus, clustering solutions have been investigated as an enabling technology [11]. Most recently, we also observe a trend towards heterogeneous networking, i.e., the use of multiple communication technologies depending on the kind of message transmission [9].

The idea of using cars and their communication capabilities to form networks has been considered numerous times: Gerla et al. propose the concept of a vehicular cloud [12]. The focus of their work is not on external users who use the services provided or enabled by vehicles, but on autonomous driving. Such a vehicular cloud should provide all sensor data and other information which is needed for autonomous vehicles. Furthermore, the establishing of clusters of parked vehicles to form an information hub has been investigated [2]. In this work, parked cars are organized using virtual coordinate based routing concepts in combination with inter-domain routing to provide network connectivity and data management. Users are then able to store data inside this network and retrieve the data later on. Another, already existing system is proposed by Barros [13], which uses mesh routing across cars to provide Internet access. Most recently, Baron et al. proposed a centralized solution that coordinates delay-tolerant transfer of bulk data, e.g., between data centers, via a vehicular network [14].

We go one step further and enable a large-scale vehicular network to provide services to other cars, outside users, and even sensor systems in future smart cities. Thus, we need to rely on specific means of identifying these services in a location-based approach.

For content identification, future Internet research has lead to concepts such as Information-Centric Networking (ICN) [15] and Named Data Networking (NDN) [16]. The idea is to associate content with unique names. The application of ICN to vehicular networks, for example, has been proposed in [17]. The authors aim to modify the WAVE stack by replacing IP with a new protocol. Therefore, this proposed protocol works only for IEEE 802.11p and not for heterogeneous networks.

Grassi et al. propose a scheme to bring the concept of NDN to the vehicular domain [18]. They evaluated their scenario with two applications and using IEEE 802.11p based communication in a vehicular testbed. Wang et al. follow the same idea [19]. They extensively evaluate a single application collecting traffic statistics using NDN. Yet, both approaches only aim for a rather limited set of applications. Most recently, a system named *Internames* has been presented [20]. All names are mapped to locations and the needed protocol to reach them. *Internames* is envisioned to work with all kinds of approaches including IP, cellular, and ad-hoc networks.

In contrast, our architecture tries to act as a base for a multitude of applications. Current ICN and NDN solutions fall short when it comes to the specific requirements in the very dynamic and disruptive environment of vehicular networks. Yet, we build upon concepts described in these approaches such as the association of items with hash tags.

III. THE CAR4ICT ARCHITECTURE

In the following, we outline the concepts of the Car4ICT architecture. We start with some use cases from which we can derive some basic requirements before discussing the architecture in depth. We conclude this section with a detailed look at the service announcement and discovery procedures.

A. Motivation and Use Cases

Let us assume we have an additional network of driving vehicles available on the road. This network would be available almost ubiquitously in future smart cities. It could also complement the available WiFi access points, hotspots on the streets, and cellular networks based on UMTS (3G) or LTE (4G), where these are available. Where no pre-installed infrastructure is available or where it is overloaded, this network would still be able to work. This additional network can be made available to users. They might also exploit the movement of a car when there is no other connection available having the cars take the information to the right spot or at least to a point where connectivity to the destination is readily available.

We envision such a network consisting of cars that act as central entities in future ICTs systems. In the proposed architecture users are able to use the network to offer and request *services*. To give some examples for such services, a user could offer storage space, unused CPU power, or access to smart sensors. Other users would then be able to request these services, e.g., to process large amounts of data on the go. In our architecture, cars also play the role of coordinators by receiving such service offers and storing them until a user requests them. The user then gets a list of others who provide the requested service. Finally, the network relays the data between the user who offers the service and the one who requested it.

A simple example use case for such a network would be a tourist who wants to quickly store more pictures than can be kept on her camera. Because she has no data plan in the foreign country, she is not able to use one of the existing cloud storage providers. In our vision the tourist is able to connect via a short range radio (e.g., WiFi or Bluetooth) to any Car4ICT-enabled car that is passing by, transmitting a request for secure replicated storage. The car quickly compiles a list of known cars offering storage and sends a reply. Now the tourist can use the Car4ICT network to store select pictures on one or more of these cars. Similarly, when the tourist is back at the hotel she can query any passing Car4ICT-enabled car to download the pictures back onto any device.

This very simple example can easily be extended to very complex ones in which smart sensors in future cities request actions such as further post-processing in order to validate measurements in disaster scenarios. As no network infrastructure might be available in this situation, the few remaining cars are able to establish a new network on demand using all available communication technologies in addition to their ability to store-carry-and-forward the data.

B. Architecture

The basic architecture we propose consists of two entities interacting with each other. The first kind of entities are the cars which create the network, the *members*. They are responsible for looking up services and propagating messages through the network. Additionally, each car can act as a gateway for the second category of entities, *users*, which connect to the network to offer and request services. Such a user might be human, e.g., a person close to a car who makes use of Car4ICT services by accessing the network using his smartphone. If a user connects to the network like this, it is most likely that he makes use of short range radio communication such as WiFi or DSRC. Another type of user would be a machine, for example a sensor in the car itself which offers temperature, humidity, and air quality readings (allowing, e.g., people to generate small scale weather and, to many of us even more important, allergen and environment pollution maps by aggregating such sensor readings in an area). Similarly, automated systems can use the Car4ICT architecture in true Machine-to-Machine (M2M) fashion. Note that a car can be both entities at the same time, for example by being member as described before while also being a user by offering some of its sensor readings.

Before being able to use the system a user has to be verified. This is done by sending a message including the user's credentials to any member (i.e., any Car4ICT-enabled car) which then replies with an individual grant. Afterwards, the user is able to offer or request services via the network. There exists a multitude of possible services covered by our architecture, e.g., data storage, distributed computing, sharing messages with a specific region, or retrieving sensor readings. Individual cars are responsible for storing known offers in a local service table and sharing them with neighbors. If a user requests a service, a car queries its local table; if not found there are different options to further enhance the success rate: The car can forward the query to other cars or cars could share their service tables proactively to reduce the possibility of failures. As some cars are also equipped with devices capable of establishing a cellular link, it could also be possible to maintain a central server via which offers can be shared by a large number of cars.

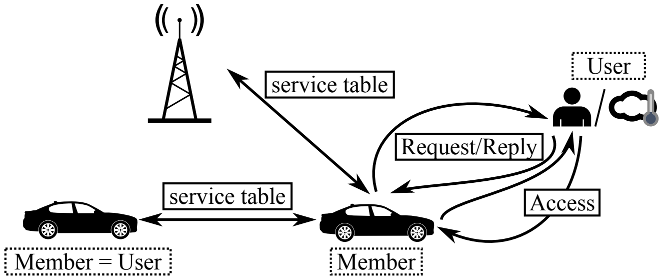

Figure 2. An overview of the control plane of the proposed Car4ICT system.

Figure 2 shows the control plane of the Car4ICT network. A user sends access messages/requests to a member, a member replies with a grant/replies. Between members the service tables can be exchanged to allow for a faster service discovery. Additionally, an offer can also be sent via a cellular network to a central repository.

We need to emphasize that the final choice of the used communication technology is up to the user. Depending on metrics like delay, connectivity, and cost, the user might want to rely on provided ad hoc communication or on a more costly LTE data connection.

C. Access Process

The typical process of a user requesting a service and getting an answer from the network is outlined in Figure 3:

1) After receiving a broadcast from a car passing by, the user may initiate the connection to the network by sending security credentials to the car.
2) The car verifies that the user is indeed allowed to use the network – this can, for example, be done using certificates. A positive answer includes an access grant.
3) After receiving the grant, the user can send a request message including an identifier of the service to the car.
4) The car checks its local service table if it already knows an entity providing this service. If it was successful, an answer is sent back including the ID of the service. If not, the car may initiate a search, first using short-range radio communication and an expanding ring search algorithm; and, secondly, if sufficient incentive exists, even using its own or a neighboring car's LTE uplink in order to locate more distant service providers. In the end the result will be a list of users who offer the service and the respective cars via which it is possible to reach the user.
5) The user receives the list of services and decides which to use, e.g., using parameters like timeliness or location to make its decision. The car network takes care of the data transfer, be it via some ad-hoc routing protocol, via store-carry-and-forward, or by using cellular connections.

D. Identifying Services

For identifying services, we selected a hash tag plus meta data based system because of its flexibility and extensibility, following the concepts discussed also in the ICN context [21].

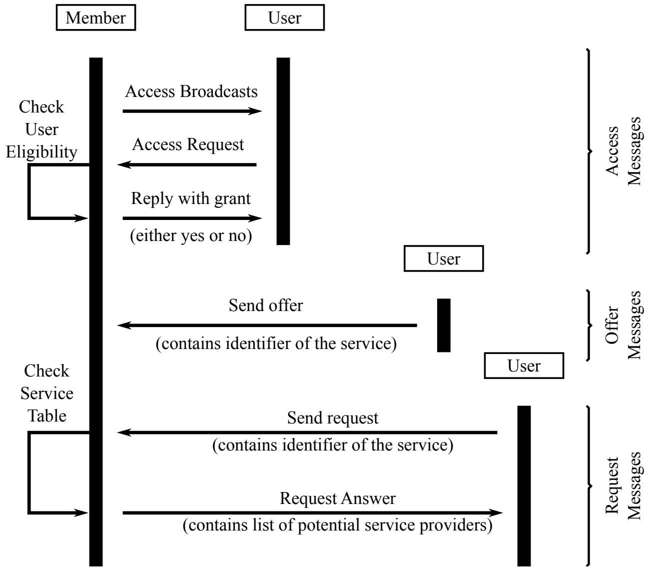

Figure 3. Offering and requesting a service.

Each service is first of all uniquely identified using a hash tag. This hash tag can either be a hash of the content, e.g., when considering a data file, or a special tag when pointing to a specific service such as CPU power, storage, or sensor readings. Using such hash tags, users and cars can already start announcing and using available services.

The hash tag, however, is not able to carry information about the geographical context and certain time constraints. Therefore, additional meta data can be added such as a location tag. The combination of hash and location tag now allows to specify location-dependent services.

Some examples services identified by their hash tag plus meta data are depicted in Figure 4. In this example, *file1* is available at three different locations provided by different users. Pictures of type *image* are hosted by two users.

In order to announce or query services, first, the corresponding hash tag has to be identified. This is done by looking up the hash in the local service table. Meta data including geographic information can be used to make the query more specific.

Hash tag	Meta data			User
hash(file1)	location = Tokyo,	type = video,	size = 2GB	1
hash(file1)	location = Tokyo,	type = video,	size = 2GB	3
hash(file1)	location = Paderborn,	type = video,	size = 2GB	7
hash(file2)	location = Tokyo,	type = image		1
hash(file2)		type = image,	size = 500MB	12
CPU	location = Paderborn,	type = ARM		7
Storage	location = Paderborn,	type = hours,	size = 78GB	7

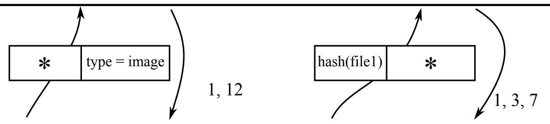

Figure 4. Three examples of identifier usage – two for an exact match using the hash and one for subset matching.

E. Service and Neighbor Tables

All the service tables stored at the cars are continuously updated. Our system considers the following options to add entries to these tables and to prune them, respectively.

1) Adding New Neighbors and Services: Members learn about new services by overhearing service announcements from others. However, this does not necessitate additional messages. All current proposals for inter-vehicle communication including the IEEE and ETSI standards assume a periodic exchange of cooperative awareness messages [22]. These messages are called Cooperative Awareness Messages (CAM) in Europe and Basic Safety Messages (BSM) in the U.S.; essentially, these messages can be regarded as a helper instrument for maintaining neighbor information. Based on this neighborhood information, we assume to be able to establish additional service tables by piggybacking this data onto these messages. If, however, a service is not yet known to a car when being searched, the car has, as previously mentioned, different options like querying neighbors or searching a central repository. Similar techniques have been used in the scope of mobile ad hoc routing protocols.

2) Pruning Outdated Information: Information about services needs to be updated from time to time. If a car has not received any update to a service, it will be removed from the table by means of a timer. As the network as a whole strongly depends on the correct association of services to geographical regions as well as to cars and users within that region, services also have to be pruned if the car leaves the corresponding geographic domain.

IV. SIMULATION STUDY

A. Simulation Environment

We developed a first version of this system for the open source vehicular network simulator *Veins*. It provides support for DSRC, while the newly developed extension *Veins LTE* [23] adds support for LTE. We performed simulations in a challenging Manhattan grid scenario. Every street was bordered immediately by buildings acting as radio obstacles. The road and building dimensions were taken from real downtown Manhattan. In the simulation we put 15 users of which five offered a service and five requested this exact service. The remaining five users send offers for different services. Table I shows the parameters used in the simulation.

B. Implemented Protocol Behavior

The following Car4ICT service discovery protocol is a proof of concept to show that, with simple steps, the idea of Car4ICT is already working:

1) Cars broadcast their position to users in a fixed interval and users are able to reply and receive a grant.
2) Preconfigured users periodically send offers that they provide a certain service. Cars store this offer in their service table and periodically exchange these tables (denoted as the *service table broadcast interval*).
3) A different set of users periodically request the exact same service.
4) If the car is aware of a matching offer the user gets this information.
5) If a user gets a positive reply to its request it logs the delay since the first request. We call this delay the *discovery latency*. In case the car did not know any user offering the service the user tries again in 2 s.

Table I
USED SIMULATION PARAMETERS.

Parameter	Value
simulated area	0.7 km^2
average number of equipped cars per km^2	85–415
total number of users	15
number of users requesting	5
number of users offering	5
IVC technology	IEEE 802.11p
IVC maximal transmit power	10 mW
simulation duration	80 s
service table broadcast interval	0.1–10 s
neighbor table entry lifetime	10 s
service table entry lifetime	10 s
user request interval	2 s
request timeout	30 s

C. Selected Results

In Figure 5 we show, in the form of an eCDF, how long it takes a user to get a successful reply for his service request with different traffic densities (vehicles per km^2). As can be seen, the traffic density influences the discovery latency. This effect can be more clearly observed in the zoomed in part in Figure 5. For high densities it takes no more than 2 s to match 99 % of service requests to a corresponding offer. For a density as low as 85 vehicles per km^2 (corresponding to a market introduction scenario), only 90 % are successfully matched in the first two seconds and 99 % in 12 s.

We therefore investigate if a smaller service table broadcast interval might help improve the system for low traffic densities. We plot the results in Figure 6, using intervals down to 0.1 s. As can be seen, exchanging service tables every 1 s

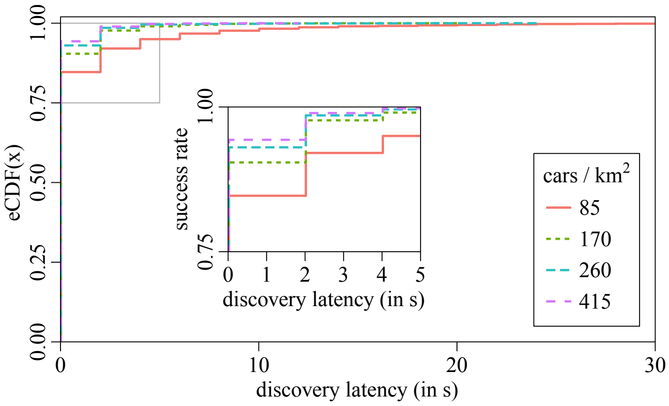

Figure 5. The discovery latency until a service is found for different traffic densities. The service table broadcast interval was set to 10 s. The inlay shows a zoom to the first 5 s.

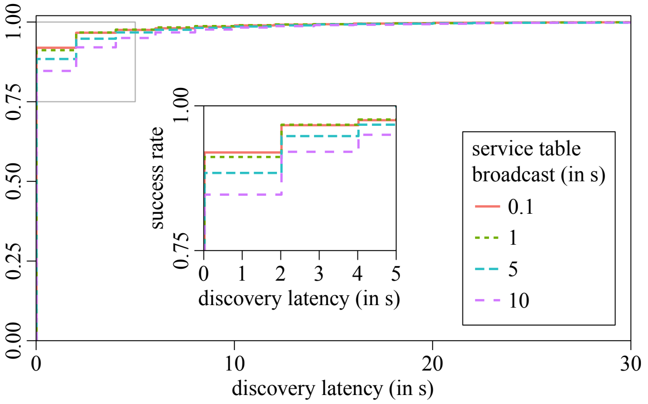

Figure 6. The discovery latency until a service is found for different service table broadcast intervals. The traffic density was 85 vehicles per km^2.

(down from every 10 s) yields discovery delays that are comparable to those of high traffic densities again: 95 % of requests can be successfully matched to a corresponding offer in the first 2 s. Decreasing the interval further yielded no substantial performance gain. Thus, even a configuration aimed at low traffic densities leaves enough channel capacity for the exchange of user data.

V. CONCLUSION

In this paper we outlined our concept for a smart vehicle-based network architecture named *Car4ICT* that can offload data from, complement, or replace existing infrastructure based solutions. We make cars the center of ICT solutions, with a particular focus on future smart cities. Users can instrument these cars to offer and request services while the cars take care of discovery and data transfer. We showed that such a flexible system is needed because currently existing concepts focus mainly on a single application scenario or assume a high penetration rate of IVC equipped cars. Finally, we were able to show with some proof of concept simulations that service discovery is fast and reliable even under poor communication and deployment circumstances. In the future, we want to employ more sophisticated algorithms and strategies to increase the performance of the system. Such additions, accompanied with better usage of identifier meta data will improve the overall performance.

REFERENCES

[1] A. Caragliu, C. Del Bo, and P. Nijkamp, “Smart Cities in Europe,” *Journal of Urban Technology*, vol. 18, no. 2, pp. 65–82, 2011.

[2] F. Dressler, P. Handle, and C. Sommer, “Towards a Vehicular Cloud - Using Parked Vehicles as a Temporary Network and Storage Infrastructure,” in *15th ACM International Symposium on Mobile Ad Hoc Networking and Computing (Mobihoc 2014): ACM International Workshop on Wireless and Mobile Technologies for Smart Cities (WiMobCity 2014)*. Philadelphia, PA: ACM, Aug. 2014, pp. 11–18.

[3] O. Altintas, K. Seki, H. Kremo, M. Matsumoto, R. Onishi, and H. Tanaka, “Vehicles as Information Hubs During Disasters: Glueing Wi-Fi to TV White Space to Cellular Networks,” *IEEE Intelligent Transportation Systems Magazine*, vol. 6, no. 1, pp. 68–71, Jan. 2014.

[4] C. Sommer and F. Dressler, *Vehicular Networking*. Cambridge University Press, Nov. 2014.

[5] M. L. Wald, “U.S. Plans Car-to-Car Warning System,” *The New York Times*, p. B3, February 4 2014.

[6] W. Viriyasitavat, S.-H. Yu, and H.-M. Tsai, “Channel model for visible light communications using off-the-shelf scooter taillight,” in *Vehicular Networking Conference (VNC), 2013 IEEE*. Boston, MA: IEEE, Dec. 2013, pp. 170–173.

[7] W. Bronzi, R. Frank, G. Castignani, and T. Engel, “Bluetooth Low Energy for Inter-Vehicular Communications,” in *6th IEEE Vehicular Networking Conference (VNC 2014)*. Paderborn, Germany: IEEE, Dec. 2014.

[8] J. Hasch, E. Topak, R. Schnabel, T. Zwick, R. Weigel, and C. Waldschmidt, “Millimeter-Wave Technology for Automotive Radar Sensors in the 77 GHz Frequency Band,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 60, no. 3, pp. 845–860, Mar. 2012.

[9] F. Dressler, H. Hartenstein, O. Altintas, and O. K. Tonguz, “Inter-Vehicle Communication - Quo Vadis,” *IEEE Communications Magazine*, vol. 52, no. 6, pp. 170–177, Jun. 2014.

[10] A. Vesco, R. Scopigno, C. Casetti, and C.-F. Chiasserini, “Investigating the Effectiveness of Decentralized Congestion Control in Vehicular Networks,” in *IEEE Global Telecommunications Conference (GLOBECOM 2013)*. Atlanta, GA: IEEE, Dec. 2013.

[11] L.-C. Tung, J. Mena, M. Gerla, and C. Sommer, “A Cluster Based Architecture for Intersection Collision Avoidance Using Heterogeneous Networks,” in *12th IFIP/IEEE Annual Mediterranean Ad Hoc Networking Workshop (Med-Hoc-Net 2013)*. Ajaccio, Corsica, France: IEEE, Jun. 2013.

[12] E. Lee, E.-K. Lee, M. Gerla, and S. Oh, “Vehicular Cloud Networking: Architecture and Design Principles,” *IEEE Communications Magazine*, vol. 52, no. 2, pp. 148–155, Feb. 2014.

[13] J. Barros, “How to Build Vehicular Networks in the Real World,” in *15th ACM International Symposium on Mobile Ad Hoc Networking and Computing (Mobihoc 2014)*. Philadelphia, PA: ACM, Aug. 2014, pp. 123–124.

[14] B. Baron, P. Spathis, H. Rivano, M. Dias De Amorim, Y. Viniotis, and J. Clarke, “Software-Defined Vehicular Backhaul,” in *IFIP Wireless Days Conference 2014*. Rio de Janeiro, Brazil: IEEE, Nov. 2014.

[15] B. Ahlgren, C. Dannewitz, C. Imbrenda, D. Kutscher, and B. Ohlman, “A Survey of Information-Centric Networking,” *IEEE Communications Magazine*, vol. 50, no. 7, pp. 26–36, Jul. 2012.

[16] L. Zhang, A. Afanasyev, J. Burke, V. Jacobson, k. claffy, P. Crowley, C. Papadopoulos, L. Wang, and B. Zhang, “Named Data Networking,” *ACM SIGCOMM Computer Communication Review*, vol. 44, no. 5, pp. 66–73, Jul. 2014.

[17] M. Amadeo, C. Campolo, and A. Molinaro, “CRoWN: Content-Centric Networking in Vehicular Ad Hoc Networks,” *IEEE Communications Letters*, vol. 16, no. 9, pp. 1380–1383, Sep. 2012.

[18] G. Grassi, D. Pesavento, L. Wang, G. Pau, R. Vuyyuru, R. Wakikawa, and L. Zhang, “ACM HotMobile 2013 Poster: Vehicular Inter-networking via Named Data,” *ACM SIGMOBILE Mobile Computing and Communications Review*, vol. 17, no. 3, pp. 23–24, Jul. 2013.

[19] L. Wang, R. Wakikawa, R. Kuntz, R. Vuyyuru, and L. Zhang, “Data Naming in Vehicle-to-Vehicle Communications,” in *31st IEEE Conference on Computer Communications (INFOCOM 2012): Workshop on Emerging Design Choices in Name-Oriented Networking*. Orlando, FL, USA: IEEE, Mar. 2012, pp. 328–333.

[20] N. B. Melazzi, A. Detti, M. Arumaithurai, and K. K. Ramakrishnan, “Internames: a name-to-name principle for the future Internet,” in *10th International Heterogeneous Networking for Quality, Reliability, Security and Robustness (QShine 2014)*. Island of Rhodes, Greece: IEEE, Aug. 2014, pp. 146–151.

[21] S. Farrell, D. Kutscher, C. Dannewitz, B. Ohlman, A. Keranen, and P. Hallam-Baker, “Naming Things with Hashes,” IETF, RFC 6920, Apr. 2013.

[22] ETSI, “Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service,” ETSI, Tech. Rep. 302 637-2 V1.3.1, Sep. 2014.

[23] F. Hagenauer, F. Dressler, and C. Sommer, “A Simulator for Heterogeneous Vehicular Networks,” in *6th IEEE Vehicular Networking Conference (VNC 2014), Poster Session*. Paderborn, Germany: IEEE, Dec. 2014, pp. 185–186.