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SPECIAL ISSUE PAPER

A survey and challenges in routing and data dissemination in vehicular *ad hoc* networks

Wai Chen, Ratul K. Guha*, Taek Jin Kwon, John Lee and Yuan-Ying Hsu

One Telcordia Drive, Piscataway, NJ 08854, U.S.A.

ABSTRACT

In this paper, we survey recent results in vehicular *ad hoc* networks (VANETs) data dissemination. We describe methods proposed to enforce dissemination scope such as geocast/broadcast and multicast. A growing category consisting of methods designed to achieve disruption tolerance in vehicular networks is presented. We describe the key ideas of representative technologies in each category. In addition, we consider location service and security issues that are crucial for data dissemination in VANET. We conclude by sharing our thoughts on further challenges. Copyright © 2009 John Wiley & Sons, Ltd.

KEYWORDS
vehicular communication; data dissemination and routing; disruption tolerant networking

***Correspondence**
Ratul K. Guha, One Telcordia Drive, Piscataway, NJ 08854, U.S.A.
E-mail: rguha@research.telcordia.com

1. INTRODUCTION

Vehicular communications have been considered to be an enabler for numerous vehicle safety and information applications. Many automobile manufacturers are in different stages of integrating communication devices in their vehicles for the purpose of safety, assisted driving, entertainment, and mobile commerce. As increasing number of vehicles start getting equipped with communication capability, large scale *ad hoc* networks can be envisioned in the foreseeable future.

Numerous projects worldwide, e.g., References [1–3] in Europe, Reference [4] in the US, and Reference [5] in Japan are actively engaged in researching and developing the infrastructure for vehicular communications and applications. The wireless access in vehicular environments (WAVE) [6] has been proposed as a standard to enable communication between vehicles and with the roadside unit (RSU). A comprehensive overview of the WAVE standard is presented in Reference [7].

Through vehicular ad hoc networks (VANETs), it would be possible to achieve flexible communications among vehicles and with roadway or infrastructure. The proposed vehicular applications have a diverse array of requirements and each has an unique set of networking characteristics [8]. Multi-hop data dissemination capability is one of the major advantages of VANET. Multi-hop dissemination can be used for extending the reach of safety and emergency warning messages, exchanging neighborhood information queries, or relaying data from the Internet, etc. Accordingly, multi-hop data flows in a VANET could result from a range of applications and can have a major influence on the design of the data dissemination technologies. Multi-hop data dissemination requires in general (1) the knowledge of node locations, and (2) a method of forwarding packets toward their destinations. This may be accomplished by two types of technologies, (a) a routing protocol [9] that performs both functions (maintaining the network topology and forwarding packets along shortest paths), or by (b) a combination of location service and a method of packet forwarding. The choice and design of the dissemination technology should be made to match the vehicle application needs, vehicle mobility, and communication assets. We survey both types of data dissemination technologies in this paper. The dissemination techniques we discuss have been proposed under the assumptions of a WAVE-based communication architecture.

We organize this paper as follows. Section 2 describes the geocast and broadcast methods. In Section 3, we describe the multicasting protocols that have been proposed for vehicle-to-vehicle (V2V) communications. In Section 4, we discuss methods proposed to achieve disruption tolerance in vehicular networks. We discuss security considerations

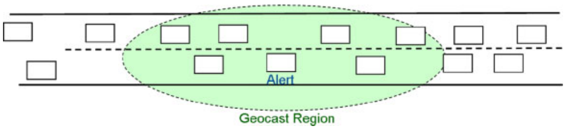

Figure 1. The Geocast region within the oval designates the relevance area of an alert message.

in Section 5 and provide an overview of challenges in Section 6. Section 7 concludes the paper.

2. GEOCAST AND BROADCAST

In this section, we present works related to broadcasting in VANETs. The primary objective of broadcasting in VANETs is to distribute information from a source to many unknown/unspecified destinations. Broadcasting is a necessity for VANETs not only for forwarding but also for delivering information without constructing a data path. Because of the multi-hop nature of vehicular networks, flooding is a fundamental mechanism to implement the multi-hop broadcasting (UMB). Various broadcast and flooding protocols [10–13] have been proposed and evaluated in terms of their reliability. Message dissemination using local attributes have been widely studied, e.g. position and direction [14], broadcast interval [15], and roadway segments [16].

Unfortunately, flooding in many cases, especially in a dense network, introduces significant communication overhead due to redundant re-broadcasting. To alleviate the well-known broadcast storm problem, most of broadcasting protocols developed for vehicular networks include efficient flooding methods; i.e., only a limited number of nodes relay the broadcasting data. In this section, we cover a part of the multi-hop broadcasting studies which are closely related to vehicular networks. Interestingly, almost all broadcasting methods in VANET utilize position information—the position information is used to identify the next relay node. We start with generic broadcasting where all connected nodes are recipients, and close this section with geocasting which is a special case where nodes in a certain geographic location as shown in Figure 1 are destinations.

Vector-base TRAcking DEtection (V-TRADE) by Sun *et al.* [17] is one of the earliest examples of broadcasting in VANETs. A vehicle classifies its neighbors into multiple classes based on the position and the moving direction. A relay node selects one border node for each class and broadcasts a packet with IDs of the border vehicles. The feasibility is limited due to the excessive control overhead to collect neighboring vehicle positioning information including vehicles traveling in the opposite direction. Urban multi-hop broadcast (UMB) [11] segments the road in the direction of dissemination and selects next relay node in the farthest segment with RTS/CTS-like signaling. Ad hoc multi-hop broadcast (AMB) [18] is a refined version of UMB. Instead of using repeaters at the intersections, AMB implements *ad hoc* branching using closest relay vehicle to the intersection. Mariyasagayam *et al.* [19] proposed enhanced multi-hop vehicular broadcast (MHVB) protocol which is another position-based flooding scheme. MHVB defines a backfire area and if a node is in the backfire area, it does not relay the broadcast packet. Given the regional information of source and destination, and road map, Wu *et al.* [20] proposed mobility-centric data dissemination algorithm (MDDV) which forwards broadcast packets in an opportunistic manner. MDDV calculates the forwarding trajectory to the destination region, and the closest vehicles to the destination within the forwarding trajectory participate in group forwarding. The group is maintained based on the vehicle location and the forwarding trajectory. Fasolo *et al.* [21] developed smart broadcast (SB) which is similar to UMB without intersection considerations. The major difference of SB is that it assigns contention windows based on the position of vehicles relative to the source. As a result, the message propagation speed is higher in SB as compared to UMB, specifically as the vehicle density increases.

3. MULTICAST

A number of safety applications require communications to a group of vehicles and not just pairwise communications as supported by unicast protocols. Efficient group communications applies to vehicles requiring notification of safety information such as intersections, road blocks and high traffic density, accidents, dangerous road surface conditions, etc. Thus, for V2V communications, multicast or broadcast schemes may be more applicable than unicast protocols. For this survey, we classify multicasting technologies, which can be applicable to V2V network environments, into two main categories: topology- and location-based approaches.

3.1. Topology-based approaches

Topology-based approaches select forwarding nodes based on the network topology information. A multicast tree or mesh is formed through a query-reply type of sequenced operations: a join-query is flooded and then join-replies are responded toward the source for the join-query. A group of members can be defined by a unique and logical group identification such as a class-D IP address: usually a multicast group is not constrained by a particular location.

On-demand multicast routing protocol (ODMRP) [22] generates a source-based multicast mesh, but multicast packets are forwarded based on the group address (e.g., destination IP address) rather than the sources of the packets. It is on-demand: a multicast mesh is created only when a multicast source has multicast packets to send. Also, it does not require any underlying unicast routing protocol. Multicast optimized link state routing (MOLSR) [23] is similar to ODMRP. The difference is that MOLSR uses the underlying unicast routing protocol to set up source-based multicast

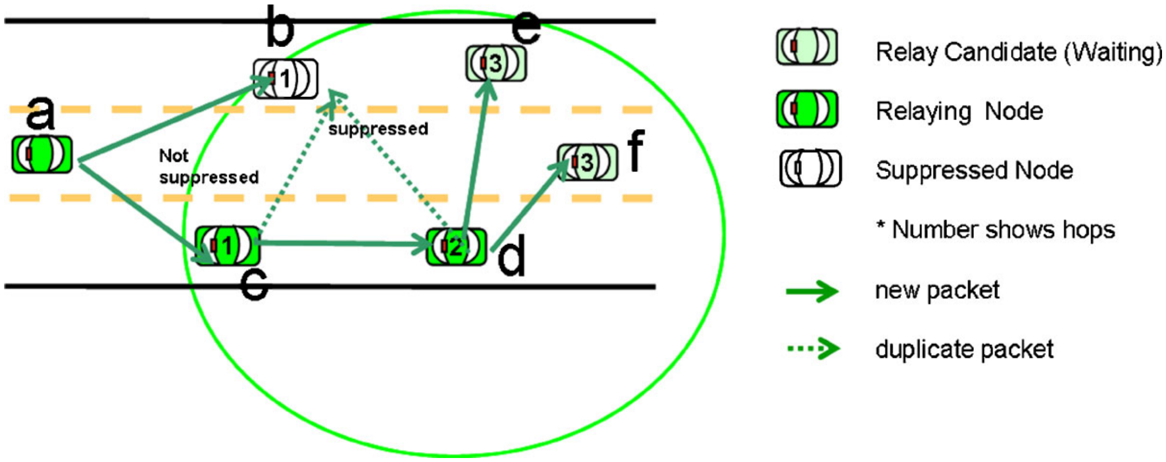

Figure 2. Group header multicast (GHM) is a proactive protocol and generates group-based multicast meshes. A suppression technique is applied to both control and data planes to reduce control and forwarding overhead.

trees and forwards multicast packets based on both the source and group addresses of a multicast session. Because of the reactive nature of these protocols, less control overhead is generated for maintaining multicast trees; but the first few packets, which are disseminated during the phase of forming a multicast tree, experience some delay and packet loss. Such delay and packet loss may not be acceptable especially for V2V safety and emergency applications which require fast and reliable dissemination of information.

Multicast *ad hoc* on-demand distance vector (MAODV) [24] generates a group-based multicast tree. It requires *ad hoc* on-demand distance vector (AODV), the underlying unicast routing protocol, during the formation of multicasting trees. Even though AODV is an on-demand unicast routing protocol, MAODV is proactive instead of on-demand: although there is no multicast source, a multicast tree is formed as long as there is any multicast receiver. While ODMRP, MOLSR, and MAODV were developed for MANET environments, group header multicast (GHM) [25] was designed for VANET environments. It is proactive and generates group-based multicast meshes (Figure 2) through periodic exchange of heartbeat and membership-report messages. The number of message exchanges does not depend on the number of multicast sources as well as the number of multicast groups, which is a significant advantage of GHM. A suppression technique is applied to both control and data planes to reduce control and forwarding overhead. Reference [26] investigated the performance of GHM in perspectives of network scalability, protocol efficiency and safety application on highway environments by comparing it with MAODV, ODMRP, and flooding. GHM performs better than those protocols in V2V network environments. According to Reference [26], although MAODV provides a reasonably good delivery ratio due to proactive and group-based multicast tree, it suffers from long delays due to link-breakage detection and recovery, route recovery operation, and unicast operations which may not be necessary in vehicle network environments.

3.2. Location-based approach

Location-based approaches select forwarding nodes based on location information such as the position of a packet sender, the position of a receiving node, the positions of neighborhood nodes, and/or the coordinates of a multicast region. Since forwarding nodes are selected during dissemination of each multicast packet, location-based approaches are reactive and do not need to maintain multicast trees—no control overhead is generated. They can be further divided into two schemes: approaches with location-independent and location-dependent multicast membership based on whether the recipients are defined through the use of location information.

We first discuss the approach with *location-independent multicast membership*. Position-based multicast (PBM) [27] requires location service (i.e., analogue of domain name service used in the Internet) to find the positions of destinations. In PBM, forwarding nodes are selected based on information about both positions of all one-hop neighbors, and positions of all individual destinations (i.e., group members) which are carried in every packet header. This may not be suitable for highly mobile and dense V2V networks in which positions of vehicles rapidly keep changing and many vehicles happen to be multicast recipients: information about the positions of vehicles becomes invalid time to time due to mobility of vehicles, and the size of a packet header would be significantly increased for carrying the position information of many recipients, which results in lower packet utilization and more packet processing as well. Accordingly, delay for packet dissemination would increase. In order to cope with the drawback of

PBM caused by many recipients, scalable position-based multicast (SPBM) [28] introduced hierarchical group membership management. The network is subdivided by hierarchical levels: a geographical region in the network can be identified by a particular combination of hierarchical levels. The multicast members in geographical regions are aggregated into hierarchical levels. The hierarchy information is carried in the packet header instead of the list of position information about all destinations. Robust and scalable geographic multicast (RSGM) [29] is similar to SPBM in the sense that the network is divided into geographical zones and multicast members are maintained through regional group membership management, but it applies position-based unicasing to forward multicast packets.

We now discuss the approach with *location-dependent multicast membership*. In location-based multicast (LBM) [30], a multicast group is specified by a particular area of region called a multicast region, and vehicles within the multicast region automatically become members of the multicast group. LBM uses information about a multicast region as destination information for multicast packets instead of information about positions of all individual destinations as used in PBM. Thus, in LBM, forwarding nodes are selected based on the position of a source and the coordinates of the multicast region. It employs a direct flooding method which limits the forwarding space for multicast packets. That is, all nodes within a forwarding zone between the source and the multicast region are responsible for forwarding multicast packets. For enhancement, LBM uses location information to partition the forwarding zone into grids and elects one forwarding node within each grid to forward packets from the source to the multicast region. Role-based multicast (RBM) [31] and inter-vehicle geocast (IVG) [32] are similar to LBM and focus on V2V network environments: they handle a specific case of multicast region which defines a multicast scope for safety warning messages in a roadway environment. They use a flooding method with distance-based timer to disseminate the warning messages to vehicles (i.e., multicast members) within the multicast region. In that sense, they are considered as broadcasting protocols for V2V communications.

4. DISRUPTION TOLERANT DISSEMINATION

Data dissemination in VANETs is significantly complicated. Due to significant network disconnections and uncertainty in mobility, the network is almost always partitioned resulting in highly unstable paths [33]. Delay tolerant networking [34] provides means to gracefully adapt to such disruptions. Various attempts [33,35] have been made to enhance MANET routing protocols by leveraging direction prediction and vehicle heading to improve performance in the case of VANETs. The methods proposed mitigate disruptions in vehicular networks by leveraging predictable vehicle mobility, known routes, navigation, etc. These methods also utilize global positioning system (GPS) information to predict route breakages and take preemptive action.

For *end-to-end communication*, various position-based forwarding protocols [36,37] have also been proposed for vehicle *ad hoc* networks. Position-based routing consists of (1) a location service [38,39] which maps node ID (IP address) to geographical position (GPS); (2) and a forwarding scheme which selects the next hop based on the geographical information of the node, neighbors, destination, and other mobility parameters. CarNet [40] proposes a scalable location service and uses it to forward packets using a geographic forwarding scheme.

The forwarding methods share the basic route discovery philosophy with greedy perimeter stateless routing (GPSR) [41]. GPSR utilizes a greedy strategy to obtain routes (Figure 3). When stuck in a local optimum, it uses a perimeter backtracking method. A requirement for this method is that the graph must be planar. Extending this in the context of vehicular networks, authors in Reference [36] point out that roadway networks in city scenarios are inherently planar. Using this observation, they propose a forwarding method greedy perimeter coordinator routing (GPCR), where vehicles at junctions decide how to forward the packets (Figure 4). The packet delivery ratio performance of GPCR is improved in GpsrJ+ [42] by predicting the road segments on to which the junction nodes forward packets to. Geographic and DTN routing with navigation assistance (GeoDTN+Nav) [43] is an enhancement to greedy forwarding protocols proposed

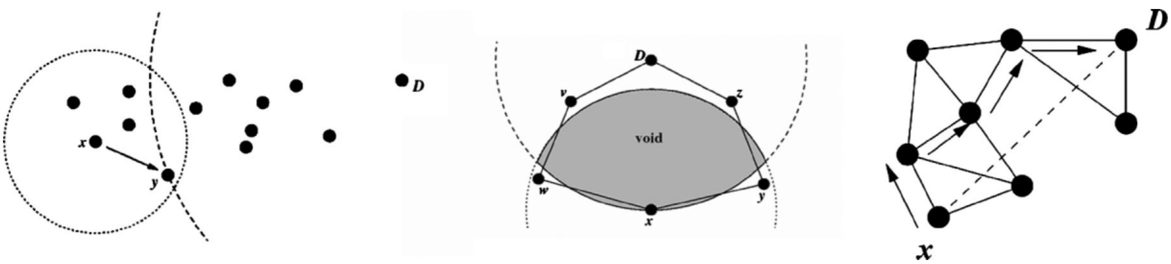

Figure 3. GPSR utilizes a greedy strategy to obtain routes. The node *x* selects the neighbor *y* which is closest to the packet destination. When stuck in a local optimum, it uses a perimeter backtracking method.

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for vehicular networks. The forwarding method uses a delay tolerant network (DTN) store-and-forward mode in addition to the perimeter mode. The decision to switch from a perimeter mode to the DTN mode is based on three factors (1) the disconnection probability as inferred from the hop count, (2) the destination and the path certainty of neighboring vehicles, and (3) the direction of travel of the neighboring vehicles. The second factor leverages predictable routes and destinations such as in the cases of public transportation (buses) and taxis.

Geographical oppurtunistic routing (GeOpps) [44] is an opportunistic forwarding method for urban grids. GeOpps uses the on-board navigation system at each vehicle to calculate the nearest point (NP) on its route to the packet destination. Each vehicle hence calculates an utility function which is the sum of the expected time to the NP and the time from the NP to the packet destination. The vehicle with the lowest value of the metric is chosen as the next carrier. The underlying assumption is that a vehicle is available at the NP to forward a packet successively to the destination. Topology-assist geo-opportunistic (TO-GO) [45] is another topology-assisted geographic routing method for urban grids.

Vehicle assisted data delivery (VADD) [46] forwards packets based on predicted roadway delays in a connected region. Minimum delay forwarding (MDF) [47] extends this notion to calculate forwarding paths that provide the minimum end-to-end delay in a distributed manner. Modified versions of topology-based routing such as modified AODV [48] incorporate vehicle speeds and other GPS parameters in routing decisions. Methods [49] have been proposed for forwarding in which flows requested by vehicles are directed to the current geographic position of the vehicle. This is achieved through flags that are set by a vehicle as it travels from one intersection to other. The flags trigger flow re-adjustments through distributed computations.

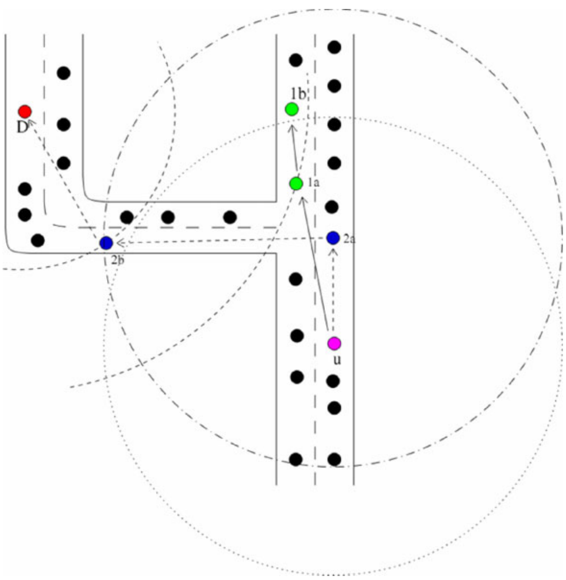

Figure 4. At node *u*, the vehicle closest to the destination is 1*a*. However, considering urban scenarios GPCR preferentially forwards packets to junction node 2*a*. Hence it is more likely for the packet to reach the destination.

Due to the dynamic nature of VANETS, it is difficult to justify the overhead of maintaining a location service in order to support unicast routing. Applications of V2V unicast routing in VANETs still remain unclear, specifically owing to the rapid development in the network infrastructure that can provide an alternative for supporting such communications.

5. SECURITY CONSIDERATIONS

Securing forwarding and dissemination is a critical issue in VANETs. Although various encryption techniques can protect the dissemination message itself, the message may not be forwarded correctly due to the multi-hop nature of VANETs. According to Reference [50], attackers could be insider or outsider, malicious or rational, and active or passive. In VANETs, routing and dissemination security issues could be divided into two categories: general attacks and position-related attacks.

General attacks, which happen to both topology- and position-based forwarding solutions, include denial of service (DoS) attacks, black hole attacks, and bogus information attack, etc. DoS attack aims to bring down the VANET through methods such as channel jamming and aggressive injection of dummy messages. Black hole attack or selective forwarding [51] is carried through a node that has the ability to lure all data around an area through itself, then simply discards all data or only forwards portion of received data. In bogus information attack, attackers diffuse false information to misguide other vehicles. General attacks except DoS attack could usually be prevented or detected by authentication. Raya and Hubaux proposed a public key infrastructure (PKI) solution [50] to authenticate sessions for either forwarding information exchange or data service transmission. IEEE 1609.2 [52] also provides a similar public key certificate to protect applications.

Position-related attacks include location falsification and sybil attack [53]. Position-based forwarding is susceptible to such attacks owing to its reliance on position information. A node can claim a faked position to pretend to be optimal than other candidates to aggregate all data as a black hole. On the other hand, a node can also create a number of virtual clones, and each claims a faked position to gain a high probability to be selected as the data forwarder. Authors in [51] provide mechanisms to secure position-based routing based on cryptographic primitives and plausibility checks. The presence of a PKI is assumed where keys are issued by a trusted certification authority [54,55].

To detect false position claim, autonomous position verification [56] treats VANET nodes as a number of independent software sensors, such as map-based sensor, overhearing sensor and uses acceptance range threshold, mobility grade threshold, maximum density threshold, to give an estimation of the trustworthiness of other node's position claims. Yan *et al.* [57] proposed to use on-board radar to detect neighbor nodes and confirm announced coordinates. Radar detection can provide higher accuracy but require extra hardware on vehicles. In a Sybil attack, the attacker's report appears to come from multiple distinct vehicles. Authors in Reference [58] propose a privacy preserving method to detect such attacks. In Reference [58], the pseudonyms at a vehicle are hashed to a common value. By calculating the hash value of the transmitted pseudonyms, a road-side unit is able to detect whether they came from the same vehicle. Reference [53] also found that the use of bi-directional antenna could help to detect sybil attack.

6. CHALLENGES

Despite the increasing body of research, the topic of data dissemination continues to be challenging. The challenge is further compounded by the absence of comprehensive comparison studies amongst different methods in the literature. A related need is the development of evaluation tools that define unified scenarios, and incorporate vehicular traffic patterns and channel models so that the merits and tradeoffs of the proposed protocols can be compared.

It is evidently hard for a single protocol to maintain a desirable performance behavior in such dynamic networks. For example, for a sparse network a blind-flooding method would be a good choice, but not for a dense network. There is a need to design dissemination techniques that are flexible to dynamic situations in VANETs. Application requirements determine the right set of QoS constraints to be triggered under any circumstance. Although a main focus in VANET dissemination design has been on delay [46,47] performance, other QoS parameters such as throughput [49] and jitter [59] have also begun to be considered in this context. The stringent requirements of safety applications are difficult to realize especially under a wide range of equipped vehicle density. Under dense situations, CDMA is viewed as a plausible candidate to provide rapid safety message dissemination as an alternative to CSMA/CA [60]. Possible low density of equipped vehicles continues to be a design challenge in many aspects and additional controls such as beam steering [61] and transmission rate selection [62] are of primary importance.

Another major hurdle is the difficulty of maintaining a location service for position-based approaches. The complexity of maintaining such services given the high mobility could suppress the potential gains. Moreover, under low equipped vehicle penetration rates, the failure rate of location services can be prohibitively high [39].

Enforcing data dissemination methods from a security and privacy-protection standpoint has received significant attention and various challenges and scenarios have been highlighted [54,55]. Finally, the involvement of the network infrastructure may also need further consideration for developing efficient V2V communications.

7. CONCLUSIONS

In this paper, we have discussed recent results for data dissemination in VANETs. In addition to dissemination methods, we have discussed security challenges in this field and the need of supporting technologies to enable efficient data dissemination for automotive applications.

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AUTHORS' BIOGRAPHIES

Wai Chen received his B.S.E.E. degree from Zhejiang University; M.S.E.E., M.Phil., and Ph.D. degrees from Columbia University in the City of New York. Currently, he is a Director and Chief Scientist at Applied Research, Telcordia Technologies Inc. (formerly known as Bellcore). He has been leading a vehicular communications research program in collaboration with a major automaker, since 2000, on automotive networking technologies for vehicle safety and information applications. He has also been the Principal Investigator of several government funded projects on advanced networking technologies research.

He is the Series Editor for Automotive Networking – Technology, Design, and Applications of the IEEE Communications Magazine, the General Co-Chair for the First IEEE Vehicular Networking Conference 2009, a Guest Editor for Special Issue on Vehicular Communications and Networks for the *IEEE Journal* on Selected Areas in Communications (2010), a Guest Editor for Special Issue on Wireless Vehicular Communications for the *Wireless Communications and Mobile Computing* (2009), a Guest Editor for Special Issue on Delay Tolerant Networks for the *Journal of Communications* (2010), and the Track Chair for Vehicular Electronics and Telematics for the IEEE Vehicular Technology Conference (2010). He also served as a Guest Editor for Special Issue on Inter Vehicular Communication (IVC) for the IEEE Wireless Communications Magazine (2006), the IEEE Distinguished Lecturer (2004–2006), the Co-Chair for Vehicle-to-Vehicle Communications Workshop (V2VCOM 2005–2008) co-located at IEEE Intelligent Vehicles Symposium, the Co-Chair for the IEEE Workshop on Automotive Networking and Applications (2006–2008) co-located with IEEE Globecom, and the Co-Chair for Vehicular Communication Technologies and Systems track for IEEE Vehicular Technology Conference (2009).

Ratul Guha received the Bachelor's in Technology in Electrical Engineering from the Indian Institute of Technology, New Delhi, India in 2002. He received the Master of Engineering and Ph.D in Electrical and Systems Engineering from the University of Pennsylvania in 2004 and 2007 respectively. He is currently a Senior Research Scientist at Telcordia Technologies, Piscataway, NJ. His research interests are in wireless networks,vehicular communications, and distributed control.

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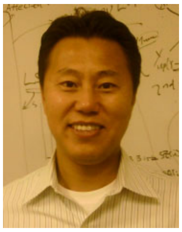
Taek Jin Kwon received the B.S. and M.S. degrees in computer engineering from Seoul National University, Seoul, Korea in 1989 and 1991 respectively and the Ph.D. in computer science from the University of California, Los Angeles (UCLA), in 2000. He is a senior research scientists in the Wireless Systems and Networks Department of Telcordia Technologies, Red Bank, NJ. His research interests include routing, security and scalability issues of *ad hoc*/sensor networks.



John Lee is a senior research scientist at Telcordia Technologies Inc. in New Jersey, U.S.A. He has been working on future military communication technologies, *ad hoc* and vehicle-to-vehicle broadcasting and multicasting protocols, and mobility handover technologies. He is a member of Eta Kappa Nu since 1989. He was the recipient of the best paper award in the 1999 IEEE Military Communications Conference. He received his Ph.D. from the Pennsylvania State University.

Yuan-Ying Hsu received her B.S. (1999), M.S. (2000), and Ph.D. (2005) degrees in Computer Science and Information Engineering from National Chiao-Tung University, Taiwan. Her research interests are mobile computing, wireless network management, wireless multi-hop networks such as mobile *ad hoc* networks and wireless mesh networks. She joined Telcordia Applied Research Center Taiwan Company (TARC-TW) as a senior research scientist in August 2005, and she is also an adjunct professor in National Taipei University of Technology from 2006. In TARC-TW, she kept her research works in mobile computing and worked with the team to implement a seamless roaming solution which supports audio streaming and VoIP sessions between heterogeneous networks. She also has research works in telematics platform and vehicular *ad hoc* networks. During this period, she participates in standard making with ITRI on IEEE 802.16j and successfully promotes several contributions to be accepted.