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INFRASTRUCTURE-ASSISTED COMMUNICATION FOR CAR-TO-X COMMUNICATION

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ABSTRACT

Vehicular communication is considered an important technology in Intelligent Transport Systems because it allows vehicles to exchange information with each other to improve road safety, traffic efficiency, and travel comfort. Several research projects have investigated the feasibility of vehicular communication using a centralized or distributed approach. The distributed approach employs short-range wireless communication such as IEEE 802.11p, positioning technology (GPS) and position-based ad hoc routing. The centralized approach relies on the wireless access network infrastructure of mobile network operators. This paper presents a survey for both approaches and discusses the advantages and disadvantages of these approaches.

INTRODUCTION

In recent years, we have witnessed a trend toward Intelligent Transport Systems (ITS) where information and communication technologies (ICT) are integrated into vehicles and road infrastructure to improve road safety, traffic efficiency and travel comfort. As a part of this trend, researchers and engineers in the automotive industry have been working toward a vision of vehicular communication technology. This technology allows vehicles to exchange information with each other to improve road safety, traffic efficiency, and travel comfort. An important ITS safety application using vehicular communication is cooperative awareness where vehicles exchange information about their location with each other to attain collision avoidance. Further, vehicles can rely on vehicular communication to provide drivers with a better perception of their surrounding and warn them about potential danger. Roadside sensor systems detecting road conditions, obstacles, or pedestrians can use vehicular communication to send their sensor data to the vehicles and warn drivers about potential hazard. Traffic light systems can also use vehicular communication to send their timing and signal phase to vehicles approaching an intersection. These vehicles can exploit this information to warn drivers about potential red light violation or adapt their speed for optimal fuel consumption. Given its various benefits, academia and automotive industry have been working on vehicular communication in recent years. Various research projects have investigated the feasibility of vehicular communication in the last decade. The majority of these research projects considered short range wireless radio (primarily IEEE 802.11p), positioning technology (GPS) and position-based ad hoc routing as the technical foundation for vehicular communication [1, 2, 3]. A few other projects have considered a different approach where vehicular communication is realized over the wireless access networks of mobile network operators [4]. With the deployment of 3GPP LTE for mobile high-speed Internet, this approach is getting more attention again due to LTE's promising performance figures for latency and throughput [6].

Independent of the underlying approach, a crucial requirement for vehicular communication is the ability to distribute information to vehicles in a geographical region. For time-critical safety information, the distribution of information must be reliable and occur in a real-time fashion. This requirement has to be considered in a dynamic environment where a potentially large number of vehicles move at high speeds and has important implications on the system design in terms of efficiency and scalability.

In this paper we analyze two different approaches for the dissemination of information in geographical areas. The *distributed* approach utilizes an ad hoc network of vehicles and roadside base stations. Data are transmitted directly among vehicles, potentially via multi-hop communication to cover a geographical region. In the *centralized* approach, a dedicated server (GeoServer) in the communication infrastructure is aware of the vehicles' and roadside units' position in a geographical area. This GeoServer transmits the information to vehicles and roadside units over the network infrastructure of mobile communication such as the 3GPP LTE network. Centralized vehicular communication is also called infrastructure-assisted vehicular communication. We discuss the advantages and disadvantages of the two approaches in terms of communication performance (end-to-end latency, network load, and target coverage) in this paper. The rest of our paper is structured as follows. In the next two sections, we provide the background of distributed and centralized vehicular communication. We then discuss the advantages and disadvantages of these two approaches. Finally, we summarize our paper.

DISTRIBUTED VEHICULAR COMMUNICATION

This approach relies on a fully distributed network of vehicles and does not require a coordinating infrastructure. The communication is based on ad hoc principles where vehicles configure themselves automatically and communicate with their neighbor vehicles to which a wireless link exists. When a vehicle detects an event (Figure 1), it defines a target geographical area and generates a message. This message is distributed via multi-hop communication within the geographical area. In order to restrict the dissemination beyond the borders of the target area, the message carries the geographical coordinates. Each vehicle compares its geographic position with the target area coordinates. For the reliable and efficient distribution of the messages, advanced algorithms have been designed. They detect message duplicates and allow for aggregation of messages from multiple sources. Messages can be stored for the lifetime of the information in order to bridge gaps in wireless connectivity and cope with sparse distribution of forwarding vehicles.

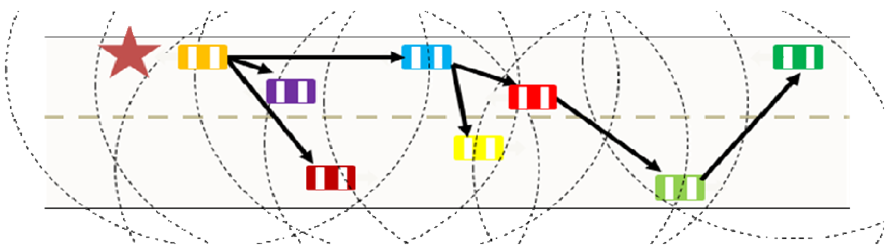

Figure 1: Dissemination of information via an ad hoc network

The core component of distributed vehicular communication is GeoNetworking [1, 2, 3], a technique that allows a sender (e.g., a vehicle) to transmit a message to a geographic area. GeoNetworking employs an addressing scheme that is based on nodes' geographical position. Using this addressing scheme, GeoNetworking implements geographical forwarding that addresses either a node by its position or multiple nodes in a geographical region. For geographical forwarding, GeoNetworking assumes that every node maintains a view of its neighborhood and that every packet carries a geographical address, i.e., the geographical position or geographical area as the destination. When a node receives a data packet, it checks the geographic address in the data packet and employs its own view of the network topology to make a local forwarding decision toward the geographic destination. Hence, data packets are forwarded on a per-packet basis and eventually reach the geographic destination in a multi-hop fashion.

Two important application messages in distributed vehicular communication are Cooperative Awareness Message (CAM) [9] and Decentralized Environmental Notification Message (DENM) [10]. CAM (also called heartbeat or "Here I Am" message) is periodically broadcast by each vehicle to inform others about its presence and characteristics. CAM is restricted to single-hop communication.

Processing CAM of other vehicles, a vehicle can gain a perception of its immediate environment. DENM is transmitted by a vehicle or a roadside station when it detects potential danger or an abnormal situation. DENM usually propagates in a multi-hop fashion to warn all vehicles within a certain geographical area. CAM and DENM are typically carried in simple datagrams that are carried by GeoNetworking on top of short-range wireless communication (e.g., IEEE 802.11p). It is worth noting that TCP/IP or UDP/IP applications can also be used in distributed vehicular communication. In this case, IP runs on top of GeoNetworking and views GeoNetworking as a layer-2 protocol. The protocol architecture of distributed vehicular communication is illustrated in Figure 2.

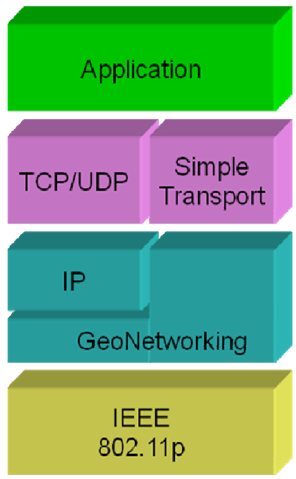

Figure 2: Protocol architecture of distributed vehicular communication.

CENTRALIZED VEHICULAR COMMUNICATION

In the centralized vehicular communication, vehicles need to associate with the roadside base stations. When a vehicle detects an event, it determines a target area and sends the associated message uplink towards a centralized server, termed GeoServer (Figure 3). This GeoServer then distributes the message to the vehicles in the geographical target area using the capabilities of the underlying communication infrastructure. Two different schemes can be employed: (i) the GeoServer is aware of the geographical position of the roadside base stations and the geographical region the base stations cover. Then, a message is distributed to all base stations in the target area and the base stations broadcast the message in their serving cell. (ii) The GeoServer maintains a location table of all vehicles with the current location. This can be achieved by the periodic location updates sent from the vehicles to the stations. Upon reception of a message, the GeoServer forwards the message to each of the vehicles via unicast communication.

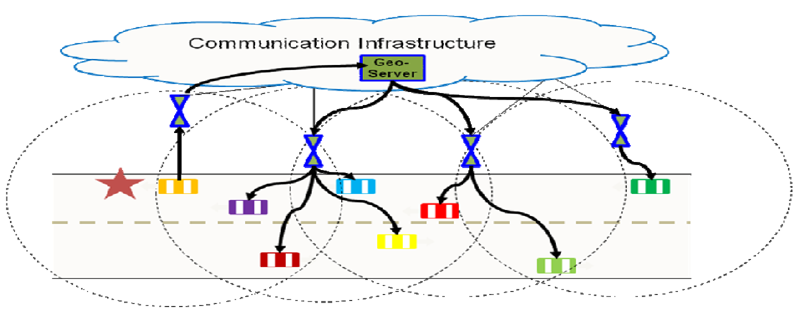

Figure 3: Information dissemination via a GeoServer

Centralized vehicular communication using a GeoServer [4] leverages the wireless access network of mobile network operator such as UMTS, HSPA, and LTE. The upcoming LTE's deployment is particularly interesting for centralized vehicular communication because LTE provides high-data rates, low latency, good geographic coverage, and full IP capability. LTE will play a key role in the next generation of mobile wireless communications. Using a GeoServer and a wireless access network such as LTE, Cellular Hazard Warnings (CHW) for safety-critical warnings can be achieved by using centralized vehicular communication. Examples of CHW include distribution of road accidents or warnings about road conditions such as black ice, bad road condition, and road works. Dynamic information such as slow moving vehicle or emergency breaking triggered by a driver can also be included in CHWs. These CHWs are contained in a TCP or UDP packet that is in turn transmitted in an IP packet. The wireless access networks such as UMTS, HSPA, and LTE build the basic communication substrate for centralized vehicular communication. The protocol architecture of centralized vehicular communication is depicted in Figure 4. TCP/IP or UDP/IP applications can run directly on top of the wireless access networks. Alternately, GeoNetworking can run on top of IP and uses a GeoServer to distribute messages over a geographical area. In this case, applications can run directly on top of GeoNetworking or relies on transport protocols such as TCP or UDP.

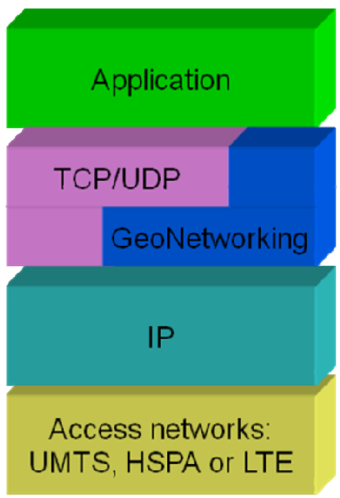

Figure 4: Protocol architecture of centralized vehicular communication.

Two options for the system architecture of centralized vehicular communication are illustrated in Figure 5. The relevant network entities and interfaces refer to the evolved packet core (EPC) for LTE networks [11]. The GeoServer is either installed in the core network of a mobile network operator (option 1) or in the Internet (option 2). In the first option, the GeoServer may exchange location information with the mobility management entity (MME) which receives regularly location update message from the connected devices, i.e. vehicles. User plane data is transported from the packet data network gateway (P-GW) or the serving gateway (S-GW) from and to the GeoServer. In option 2, the GeoServer is located in the Internet and thus decoupled from the mobile operator network.

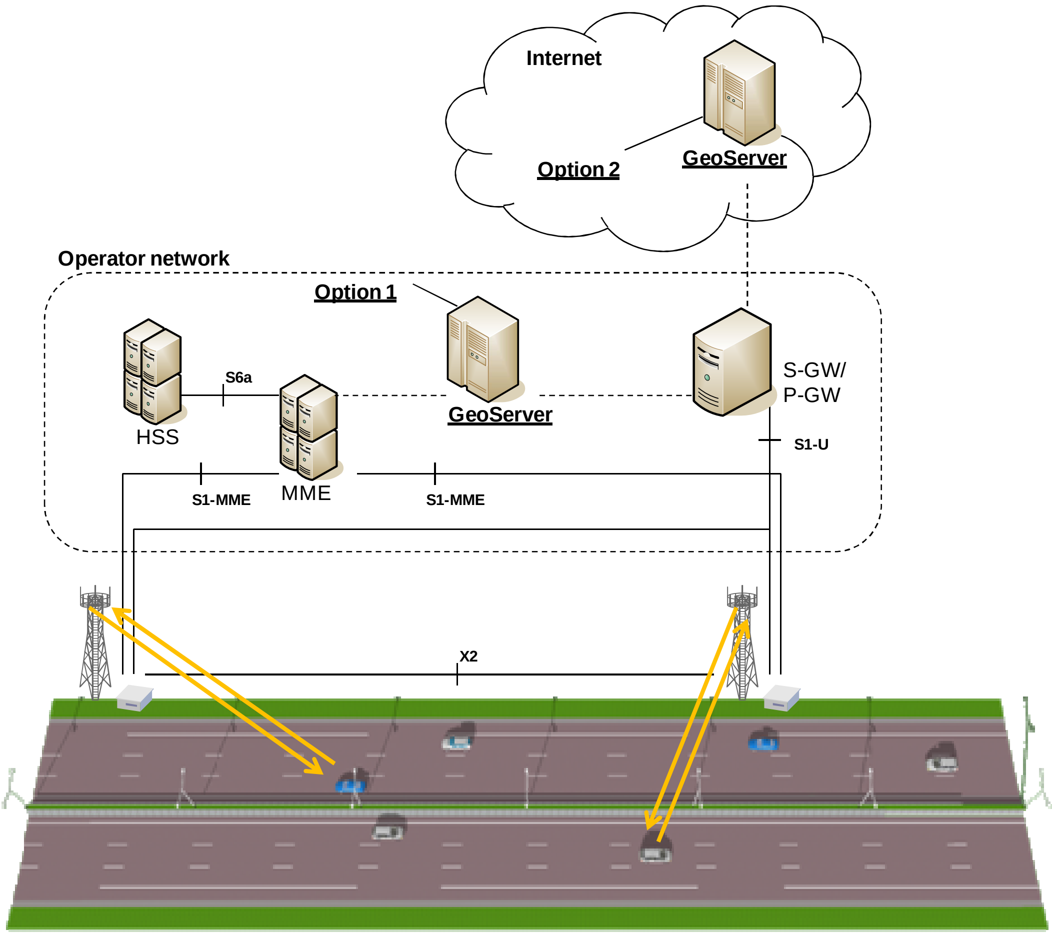

Figure 5: System architecture options for centralized vehicular communication.

Each vehicle maintains a connection to the GeoServer and regularly sends updates about its position to the GeoServer. In this way, the GeoServer is aware of all vehicles' current position. The GeoServer offers different functionalities for centralized vehicular communication.

- Reflector: When receiving a road incident message from a vehicle, the GeoServer redistributes the message back to all vehicles within a geographic area. The message content is not modified in this case. The selection criterion for the recipients of the message is the vehicles' position and the geographic relevance of the message. The redistribution of the message is done either via cellular broadcast such as the Multimedia Broadcast Multicast Service (MBMS) feature in UMTS and LTE or via multiple unicast connections to each connected vehicle.

- Aggregator: The GeoServer consolidates all road incident messages and even also with external information from other sources (if available). When traffic jam occurs, it is possible that local information sent by multiple vehicles contributes to a better global view of the roads. Thus, by consolidating the received messages, the GeoServer can derive a better or more global view of the road traffic. The GeoServer then distributes the attained view back to the vehicles for which the information is deemed relevant.

The GeoServer uses different kinds of application protocols to exchange messages with the vehicles.

- Fast Traffic Alert Protocol (FTAP) transmits short time-critical safety messages. These messages are typically less than 100 bytes and demand low transmission latency. The

GeoServer serves as a reflector for these messages.

- Non-time-critical data can be aggregated by the GeoServer and encoded in Transport Protocol Expert Group (TPEG) format. The GeoServer functions as an aggregator for this data and transmits the aggregated data to the vehicles.
- Traffic Probe Data Protocol (TPDP) allows vehicles to transmit non-time-critical traffic probe data to the GeoServer in the uplink direction.

DISCUSSION

The previous sections provide background material for centralized and distributed vehicular communication. Since they follow different approaches and system design, they have different advantages and disadvantages. We discuss these advantages and disadvantages below.

- Distributed vehicular communication relies on direct communication among vehicles using short-range wireless communication where the distance between the sender and a receiver is only a few hundred meters. For this reason, distributed vehicular communication can achieve low end-to-end communication latency (10 – 100 ms). Centralized vehicular communication depends on the wireless access networks of a mobile network operator such as UMTS, HSPA, and LTE. These networks are hierarchically structured, as illustrated in Figure 5 on the example of LTE: user plane data is transported to a central aggregation point (the P-GW) and then back to the radio access network in case of vehicle-to-vehicle communication. Without architectural enhancements, this may inflict significant latency penalties in the range of several hundred milliseconds. Further, centralized vehicular communication based on cellular networks require network attachment and bearer setup procedures before user data can be sent, which also adds to the latency. Finally, LTE does not yet support direct communication among vehicles but uses the GeoServer as a reflector. In summary, end-to-end communication latency in centralized vehicular communication may have significantly higher latency values. Hence, applications with stringent latency requirements tend to prefer distributed vehicular communication.
- When the frequency of the transmitted messages or the number of vehicles is large, the access network or the GeoServer can be overloaded resulting in poor communication performance. However, centralized vehicular communication can still be used if capacity is carefully planned and proper prioritization is supported.
- When the geographical target area of a message is large, centralized vehicular communication is a good choice because the wireless access networks have a better communication range than the short-range wireless communication used by distributed vehicular communication. Further, if the vehicle density is low, direct communication among vehicles or multi-hop communication might not be feasible.
- In centralized vehicular communication, a tunnel for each vehicle has to be created between the P-GW and an eNodeB serving the vehicle. This tunnel has to be maintained as long as an application installed at the vehicle needs to send or receive data. Thus, if centralized vehicular communication is used to transmit and receive periodic CAMs, a high load of signaling maintenance can ensue at the P-GW. However, future architectural enhancements in 3GPP can remedy this problem.

In summary, distributed vehicular communication is appropriate for applications that need to exchange information of local relevance in a real-time manner. On the other hand, centralized vehicular communication is suited for the distribution of non-real-time information over a large geographic area. These two approaches complement each other well.

SUMMARY

Vehicular communication is considered a key technology in Intelligent Transportation Systems because it enables vehicles to exchange information with each other to improve road safety, traffic efficiency, and travel comfort. Safety applications involving vehicular communication are danger warning and cooperative awareness where vehicles exchange information about their location with each other to attain collision avoidance. Several research projects have investigated the feasibility of vehicular communication using a centralized or distributed approach. The distributed approach relies on short-range wireless communication such as IEEE 802.11p, positioning technology (GPS) and position-based ad hoc routing. The centralized approach leverages the wireless access network infrastructure of mobile network operators. This paper provides a survey for both approaches. Further, a discussion about the advantages and disadvantages of these approaches is provided. Distributed vehicular communication is appropriate for applications that need to exchange real-time information over a small geographical distance. Centralized vehicular communication is suited for the applications exchanging non-real-time information over a large geographic area. In our view, these two approaches do not compete but complement each other. Future architectural enhancements in 3GPP can improve the performance of centralized vehicular communication.

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