論文 Architecture for Vehicle Safety Communication (VSC)*

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Recently, communication for vehicles has been considered for improving vehicle safety. We propose a new communication architecture model for automatic driver assistance to avoid vehicle collisions. The architecture design takes into consideration the advantages of wireless communication relative to other vehicle equipment (e.g. sensors). Communication is used to obtain indirect information and gather awareness required for automatic avoidance of danger. The architecture has the following benefits: multiple concurrent safety applications use a common and compatible set of communication functions, high importance messages are given high priority even in busy networks, and the system is flexible to work in different vehicle and traffic situations. Key software components of the distributed architecture were implemented in the scope of ad hoc Wireless Local Area Network (WLAN). The object-oriented components include broadcast multi-hop routing and an adaptation of emerging Quality of Service (QoS). These are flexible for our ongoing research and future prototyping. The software was added to the Network Simulator (ns2) platform. Key vehicle safety scenarios were evaluated in initial computer simulation experiments and results show successful adaptation. We also show how to minimize time delay for high priority messages that use indirect (multi-hop) communication.

Key words : Vehicle Safety Communication, Mobile Ad Hoc Networks, Automatic Driver Assistance Systems

1. INTRODUCTION

Vehicle safety applications are currently hot research topics. However, there are hundreds of such application concepts. It is critical to focus on the highest priority applications for maximum benefit to safety. Analysis has shown that high priority applications like cooperative collision avoidance, electronic emergency brake light signaling, and lane change assistance will require new technology.

Adaptive Cruise Control (ACC) systems have recently become available to automatically maintain distance to preceding vehicles using front sensors like laser radar. These technologies (or sensor fusion) could be applied to other cases like a vehicle that stops its driver from turning left when there is an oncoming car approaching.

Sensors have advantages of providing almost immediate information for line-of-sight obstacles and require no equipment in road structures, obstacles, or other vehicles. To prevent many kinds of accidents, we also need to detect distant objects (beyond obstacles) and obtain information about what will happen in the near future (even if estimated) or what happened in the recent past. Sensors can only directly detect what is currently there. Indirect capabilities are provided by radio communication.

Communication can take different forms. "Single-hop" means a roadside Access Points (AP) (for example on light posts) transmits messages to vehicles (or the other way) or vehicles transmit to other vehicles. "Multi-hop" networking is more indirect, meaning a vehicle transmits to another vehicle (or AP) that then transmits to another and so on. Efficient multi-hop broadcast has been shown to be challenging (NP-Hard)[1] and there are many applications and situations to consider.

Nevertheless, communication is key for automatic driver assistance systems to cooperate and plan avoidance of accidents. Together, vehicle control systems, sensors and communication will provide both direct and indirect information to warn drivers and plan automatic reaction (e.g. steer or decelerate). Therefore, a simple standard architecture with both indirect and prioritizing capabilities is desired.

Section 2 introduces a high-level vision of the role of communication for safety. Section 3 explains development of a standard architecture. Section 4 shows the architectural model and Section 5 shows results of adapting emerging technology.

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2. VISION OF SAFETY COMMUNICATION

2.1 How to solve vehicle safety problems

To avoid accidents we must first detect danger. Sensors and communication are alternatives for detecting. Sensor is a good choice for direct information. Communication is good for indirect detecting. **Figure 1** compares direct and indirect.

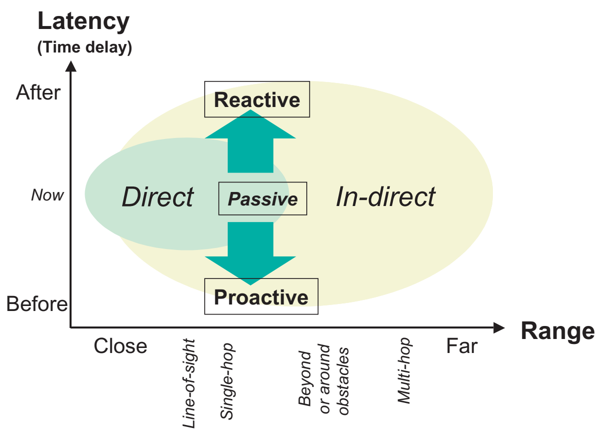


Fig. 1 Concept of direct and indirect

Second, to avoid danger we must decide how to act. A driver might receive a warning like a flashing icon or sound over the stereo system and then have to quickly interpret it and study the situation to decide what to do (top left of **Fig. 2**).

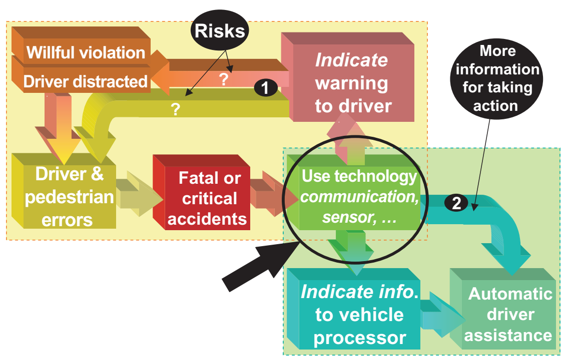


Fig. 2 Information for automatic assistance

Warnings alone cannot eliminate vehicle dangers. The reason is that drivers are not removed from the equation. Automatic driver assistance, even if limited, is necessary (bottom right of **Fig. 2**). This is more comprehensive than the common focus on warnings. Automatic driver assistance will need information to decide a safe action. For example, stopping can be more dangerous than continuing driving to avoid collision.

There are three levels of vehicle safety assistance:

1. Proactive: Automatically assist a driver to stop any driver action before a dangerous condition occurs,
2. Passive: Detect a probable collision and warn the driver (the driver must act to stop the collision), or
3. Reactive: Automatically decide how a car should act after a dangerous condition is detected (e.g. airbag).

Different information is needed for each of the above. Passive (2), is the easiest but least effective. Only immediate sensing is needed. The others are difficult because information is needed. For reactive, information is needed about (i) situation details and (ii) future action of other vehicles. The vehicle computer needs to be aware of what a driver should be aware of, and more. Information about future action is even more important for implementing proactive (1) functions to automatically assist the drivers by having their vehicles cooperate.

2.2 Which technology is necessary

Communication should not be used when it is determined to be unnecessary or less effective than sensors. Also, it should not be used to confuse or mislead drivers. For example, does it make sense to tell a driver that a traffic light will change color in 2 seconds? Is it necessary to communicate road curve angle when maximum safe speed is enough? In these "direct" situations it is not always necessary. However, communication is necessary for "indirect" situations. For example, to learn about a car that is braking hard and is several cars ahead on a highway.

2.3 Challenges to safety communication

Since indirect communication is valuable for safety purposes, we are concerned with the related challenges (**Table 1**):

1. Time delay ("Latency"): Indirect means long delay.
2. Information amount: Many applications and long range means busy and shared network.
3. Flexibility: Dynamics means a changing network.

In particular, we are concerned with limits of communication technology so we can plan products. Therefore, we started studying technical feasibility and countermeasures.

Table 1　Relation of sensor and communication

Aspect	*Sensor*	*Communication*
Latency	Very low	Low-medium
Range	Short/Direct	Short or Long/Indirect
Users	Unlimited	Limited
Main use	Detect/ Image	Message/ Information
Counterpart	Not necessary	Other vehicle or AP

3. DEVELOPING A SERVICE MODEL

3.1 Development process

Analysis showed that highest rank applications such as emergency electronic brake light signaling, cooperative collision avoidance, and lane change assistance requires vehicle-to-vehicle-to-vehicle or "multi-hop" broadcasting with low latency and flexibility for changes in network topology (i.e. how many and which cars are involved). Our unique approach considers that often there are alternative ways to accomplish an application and the choice can influence implementation of other applications.

Figure 3 is a high-level diagram of our process. We surveyed application requirements (1a) and communication capabilities (1b) and compared them to determine candidates (2) and shortcomings. For example, many applications require latency of 50ms - 200ms. We prioritized the shortcomings for technical feasibility research (3) to seek detailed measurements so that we can develop effective countermeasures (4). We want to adapt existing or emerging technology and develop algorithm or protocol countermeasures where most effective.

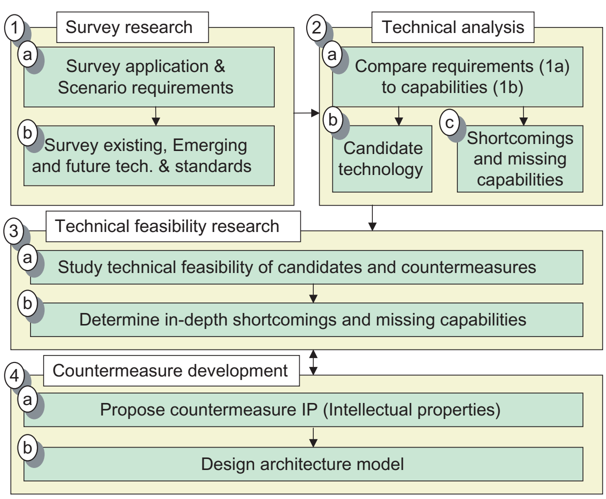


Fig. 3　Approach for feasibility research

3.2 Abstraction of requirements for services

Even though there are many safety applications, we determined common needs for communication components. For example we classify network needs in two categories:

1. Scheduled (planned communication need), or
2. Event-driven (unplanned communication need).

These can be repetitive (periodic) or not repetitive.

Figure 4 shows cooperative and indirect communication examples in these categories. Example 1 shows two cars (red and blue) that communicated their position and motion repetitively. Each vehicle computer automatically collects information from internal systems and transmits data messages every 200ms. The computer in each vehicle uses the information to automatically control a lane change. Example 2 shows several cars that automatically communicated when an unexpected emergency braking event occurs (blue car). In example 2, the far right (green) car receives indirect indication of the event from across multiple "hops" between vehicles. The automatic driver assistance system can start slowing down this car even before it could sense the other cars slowing down. If we can develop a solution for one high importance application that belongs to a class of service that we defined then we can use this solution for other applications in that class.

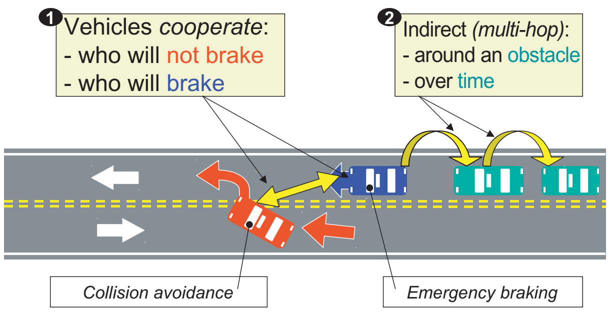


Fig. 4　Examples of cooperative and indirect communication

Figure 5 shows this conceptual idea of the relationships. Each application can have alternative service classes. Each class can have different requirements in each category. The requirements might be achieved with different compatible or incompatible implementations because of different dependencies.

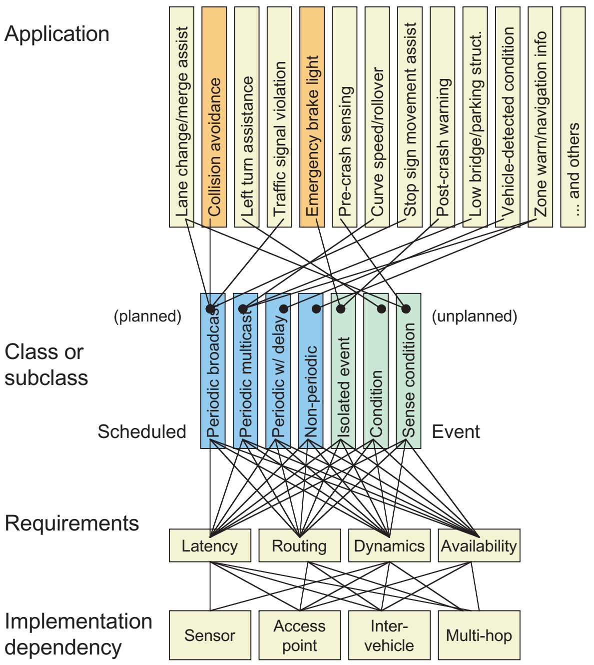


Fig. 5　Abstraction of application services

3.3　Technical feasibility research

Communication should be very frequent so that vehicle systems are fully "aware" of the environment. Like sensors, communication should always be on because there is always a possibility of accident (just like a driver should always be watching the road). This issue is important also because with so many applications (safety and non-safety) it would be impractical to dedicate separate radios for each application.

Therefore, the capability for frequent communication with low latency should be verified. We plan to adapt emerging technology as much as possible and develop countermeasures for shortcomings. Our results will be used to refine the model.

Therefore a common architecture needs flexibility for change:

- Vehicle density/Spacing (sparse or dense traffic)
- Traffic conditions (for example: fast or slow speed),
- Equipped percentage of vehicles (how many vehicles have the safety equipment), and
- Applications at the same time (one or many).

A flexible communication solution is key to long lifecycle as products will evolve and operate with newer products. Therefore, we plan to characterize limitations and deficiencies before and after adaptation of countermeasures.

4. COMMUNICATION ARCHITECTURE MODEL

4.1　Architecture components

A general architecture model with multiple "layers" is shown in **Fig. 6**. We show two examples of application classes: scheduled (left) and event (right) in the top layer. Others are studying individual applications so we are more concerned with studying multiple (two or more) applications together.

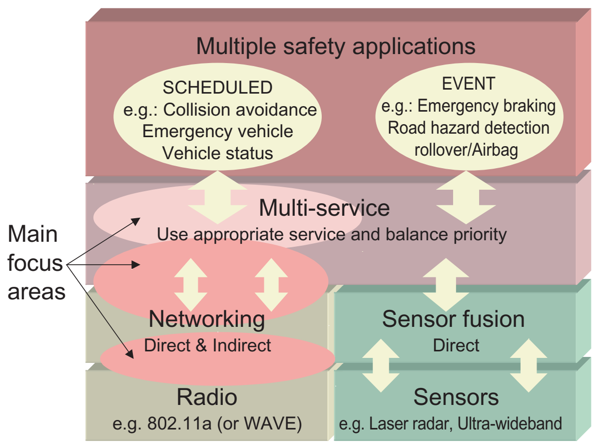


Fig. 6　General architecture model

Note that our definition of classes, like "scheduled", refers to the requirement of the communication and not necessarily the application characteristic. For example, after detected, a road condition caused by an event (e.g. slippery road caused by rain) can be communicated periodically to nearby vehicles.

Different types of applications can use different services at the multi-service layer. The multi-service layer balances priority of different services given available options at lower layers. The services use communication networking to cooperate, increase awareness and communicate indirectly (e.g. by multi-hop). The networking services use the radio to communicate with other vehicles (**Fig. 6** bottom left). We focus mainly on inter-vehicle communication because putting access points everywhere an accident might occur is not very practical.

Networking involves routing, meaning algorithms and protocols that get a message from the source to the target through intermediate vehicles. For safety, smart multi-hop broadcast (flooding) is effective because low latency and flexibility are required. Broadcast is also robust and uses the natural broadcast aspect of radio communication.

In this work our scope is vehicle-to-vehicle broadcast and multi-hop networking. The scope is limited to Wireless Local Area Network (WLAN) that uses Carrier Sense Multiple Access (CSMA) technique (like 802.11a). The IEEE 802.11 standard has emerged as a popular technology. 802.11a formed the basis for the ASTM Dedicated Short Range Communication (DSRC) standard related to the recently formed 802.11 Wireless Access Vehicular Environment (WAVE) Study Group.[2)3)]

WLAN has a distributed access method called Distributed Coordination Function (DCF) that can be adapted for vehicles in an ad hoc mode without an AP. However, it does not have Quality of Service (QoS) or prioritization capability.

4.2 Adaptation of components for vehicle safety

Our focus areas are shown in **Fig. 6**. It includes identification of areas where algorithm and protocol countermeasures are required in:

1. Multi-service: Scheduled and event,
2. Communication networking: Broadcast & multi-hop,
3. Adaptation of the radio: Prioritization, QoS.

At the network layer, we focused on applying scheduled broadcast and event-driven ad hoc multi-hop. At the Medium Access Control (MAC) layer we focused on adapting a prioritization method.

The 802.11 MAC is used in derivatives like 802.11a/b/g and has a contention-based origin. This means access to the wireless channel is an ad hoc "competition". Therefore, it has difficulties for real-time broadcast in inter-vehicle networks. Contention-based methods depend on sensing the state of the wireless channel, which is typically not well modeled as having a single state over any significant area due to path loss and spatial diversity. This causes problems like blocking and "hidden" or "exposed" terminal interference. Handshaking and acknowledgment exchanges overcome some of these, but are not available with broadcast.

4.2.1 Quality of service and prioritization

As a countermeasure for real-time broadcast, we chose to adapt the emerging 802.11e QoS standard to achieve prioritization at the networking/radio layer. This standard is in development stages (mainly for multimedia) and not yet published. However, 802.11e provides best-effort QoS for 802.11 and we adapt it to two main vehicle features: (i) local prioritization between applications at each vehicle (**Fig. 7** "triage") and (ii) prioritization between vehicles. These use the Enhanced Distributed Channel Access (EDCA) of 802.11e.

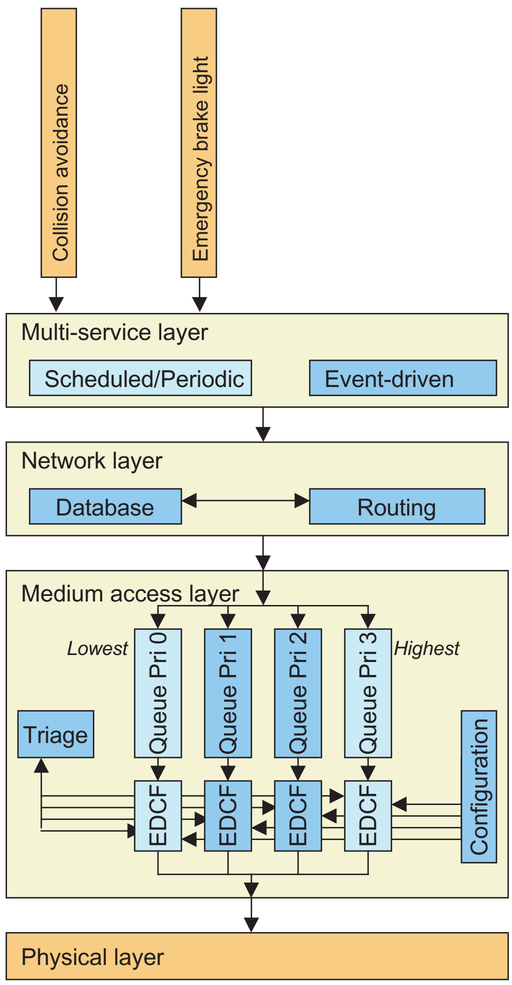


Fig. 7　Radio adaptation for vehicle safety

We studied feasibility using two examples of services (**Fig. 7** top). Initially, for multiple concurrent applications, we approximate both as periodic even though we plan to extend to two different classes concurrently (scheduled and event) in following work. Each has a priority that is used to map each message to a queue corresponding to an Access Category (AC) (we use lowest and highest). Each AC within a radio has a separate channel access function called an Enhanced Distributed Coordination Function (EDCF) and different maximum delays. Competition between messages generated in a vehicle is handled by delaying the message from the lower priority AC with a random "backoff" time period.

The 802.11e EDCA uses an Inter-Frame-Space (IFS) for prioritization. Unlike 802.11 IFS, the EDCA Arbitration IFS (AIFS) depends on AC. Each station uses Carrier Sense (CS) (virtual or physical) for an AIFS period before transmitting. Our work is unique because we investigate the applicability of this to broadcast multi-hop networking.

5. EXPERIMENT AND RESULT

5.1 Simulation of vehicle communication scenarios

Currently, experimentation in the field with many vehicles and situations has safety, implementation and cost challenges. Simulation is a practical and flexible alternative for our advanced investigation that is fast, cost-effective, and re-usable. Network Simulator (ns2) is a widely used research platform ideal for cutting-edge research in communication.[4] We developed our scenarios and object-oriented software components of our architecture in the ns2 framework (**Fig. 8**):

1. Multi-hop broadcast networking
2. Adaptation of QoS MAC (802.11e EDCA)
3. Vehicle movement and messaging scenarios

We also adapted the existing ns2 radio simulation to model 802.11a performance at 6Mbps in the DSRC 5.9GHz band.

We simulated a wide range of scenarios and here we report the important results for latency in general direct and indirect situations. Simulations were conducted using a moving window model that follows a set of vehicles (average 100km/h) indefinitely on a two-lane road. The vehicle distribution conforms to classical models by maintaining relative speeds randomly to achieve a Poisson distribution. In our initial simulations, vehicles did not yet automatically react to information received by communication.

Figure 8 shows our work for the simulation. We used application scenarios to create software models of the vehicle movements and messaging parameters (sources, timing and size) and design a range of different scenarios (to test different settings such as vehicle density). We designed object-oriented C++ modules for the router, application agent, and MAC (our 802.11e QoS adaptation) based on our architecture model. We integrated these into the ns2 platform and executed a range of scenarios to obtain a record (log) of the communication messages including latency (time sent/received by each layer) and losses (due to busy queue, busy wireless channel or out-of-range). This data was used to extract statistics on latency and losses for each scenario. That data was then combined to graph relationships of results to scenario configurations.

The ns2 animation was also modified so that we could visually observe the different priorities and ranges traveled by each message according to its color (**Fig. 8** bottom left screen shot).

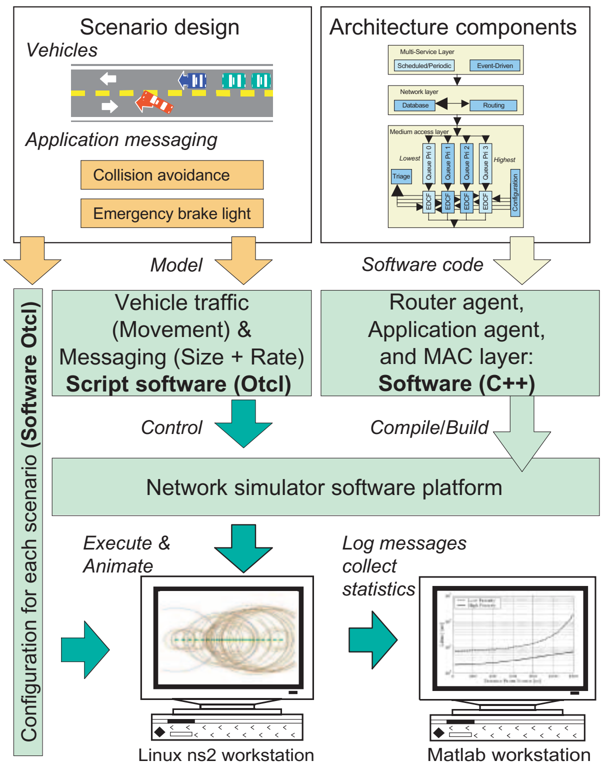


Fig. 8　Work required for simulation

5.2 Results without QoS

First we compared message latency in direct and indirect communication without QoS. Two vehicles had application agents generating messages every 200ms. **Figure 9** shows the relation of latency to vehicle spacing. It also shows the relation to message size for direct (single-hop) and to range from the source (event) for indirect (multi-hop).

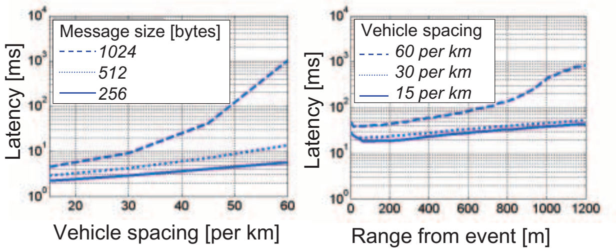
The results show the broadcast latency for periodic transmissions is almost directly proportional to vehicle density. Typically it can be low when there are few vehicles and high data rates are used with short transmission range (low power).

The influence of these factors is much more dramatic with indirect communication (smart multi-hop flooding). The accumulated latency over range from a single source vehicle (transmitting a message every 100ms and therefore the same messaging as two vehicles at 200ms), as plotted in **Figure 9 (b)**, is considerable and confirms our concern even using high data rates. For example, the impact would be even more severe with channel switching (proposed for some future DSRC standards), if only part of a channel is usable for safety, or data rate is reduced to increase transmission range.

5.3 Results with QoS

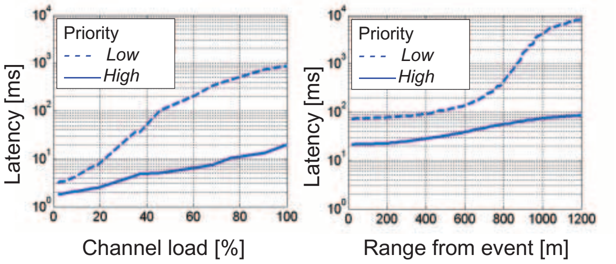
Second we did the same comparison when using QoS. One application source was assigned lowest priority and the other was assigned highest priority (AC). The total amount of messaging (bytes) does not really change but latency can be reduced for the higher priority information. Latency for lower priority information is, in tradeoff, negatively impacted.

Figure 10 presents a simplified comparison where we represent the influence of many factors such as data rate and message size as a percentage of the theoretically available channel capacity in an area around the vehicles ("Channel Load"). This also means we can easily predict performance in other configurations using this convenient generalization. For example, **Fig. 10 (a)** and **Fig. 9 (a)** 1024 byte case are directly comparable. Also, **Fig. 10 (b)** and **Fig. 9 (b)** 60 vehicles per km case are directly comparable.



(a) Direct　　(b) Indirect

Fig. 9　Latency relationships without QoS



(a) Direct　　(b) Indirect

Fig. 10　Latency relationships with QoS

Broadcast latencies strongly depend on the QoS (802.11e) parameter values (AIFS and back off). **Figure 10** shows the latency differences between the messages of the low priority application and the high priority application. It is clear that dependence on channel load is log-linear for high priority. However, low priority messages are delayed more in favor of maintaining a bounded low latency value for high priority.

The results for direct broadcast show how the difference occurs even at relatively low channel loads (**Fig. 10 (a)**). **Figure 10 (b)** shows the result of using the priority QoS functions for multi-hop. The latency impact of priority over extended ranges is key for indirect communication. These results show successful control of latency by using different priority for important messages.

The results confirm adaptation of QoS to vehicle safety purposes and can be used to plan service for multiple applications that have strict latency requirements (typical of most safety applications). Our platform can also now be used to experiment with multiple service classes concurrently.

6. CONCLUSION

This paper presented a new architecture model for effective vehicle safety communication that uses service classification, prioritization and distributed multi-hop ad hoc broadcast. Flexibility is a key requirement for cooperative and indirect inter-vehicle communications and, in particular, availability of multiple concurrent safety applications.

The architecture model was used in our more focused feasibility research into prioritization of two applications: one requiring planned periodic messaging and the other requiring unplanned messaging for a dangerous event. The model is broad and can be used in other focused research into other layers and services. Also, since we characterized application requirements into classes, the research we conducted on example applications can be extended to others.

We presented feasibility research involving implementing software algorithms for the network layer and MAC layer (adaptation of 802.11e QoS function) of the architecture. The C++ agents and OTcl script software was implemented in the ns2 platform. This software can be used in future research, verification of countermeasures and as a model for field prototypes. We are planning to extend our simulation to include automatic vehicle assistance using received messages.

We presented initial results of prioritization for multicasting safety information over direct and multi-hop ranges and demonstrated vehicle safety communication network modeling can provide a practical and effective way to analyze shortcomings and alternatives. We showed exactly how vehicle spacing (density) and channel loads contribute to latency in single-hop broadcast scenarios and how to get very low latency for a subset of messaging by prioritization in multi-hop scenarios. The results can be used to predict field performance far in advance of prototype availability.

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