# Wireless Communication Enabling Technologies for Intersection Decision Support System

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## *Introduction*

Wireless communication technologies have a key role in the development of an Intersection Decision Support (IDS) system. Wireless Communication increases the amount and quality of the information IDS system receives. Even in an Infrastructure Based implementation, the IDS application may gather critical information from the vehicles and deliver targeted warnings via wireless communication. Basically the Communication Subsystem provides two services:

- Neighborhood state amp building, i.e. to acquire information of the surrounding environment;
- Message delivery, i.e. to deliver warning or support messages.

The IDS application makes its decisions on basis of current knowledge of the surrounding environment (e.g., the application warns others of a vehicle violating the red signal if it knows that the signal phase is red and the vehicle is not predicted to stop). This knowledge is traditionally acquired via sensors. We plan to consider communication as well as sensors in the information collecting/sharing. We envision this approach to be able to overcome some sensors' limitations (e.g., it may be difficult for sensors to detect a vehicle coming from an intersecting road if there are buildings or trees near the intersection).

Wireless communication easily solves the "line of sight" problems coming with sensors: a message of the list of the vehicles approaching the intersection may be sent by the infrastructure. As soon as the IDS application makes a decision (e.g., it decides to warn a red traffic signal violator) it needs to communicate with the driver. This may be done in many different ways such as using DII or in-vehicle displays. Communication is needed to deliver these messages from the IDS application to the right device.

We will organize our enabling research around two communication architectures, a distributed architecture (Figure 1) and a partially centralized infrastructure supported (PCIS) architecture (Figure 2).

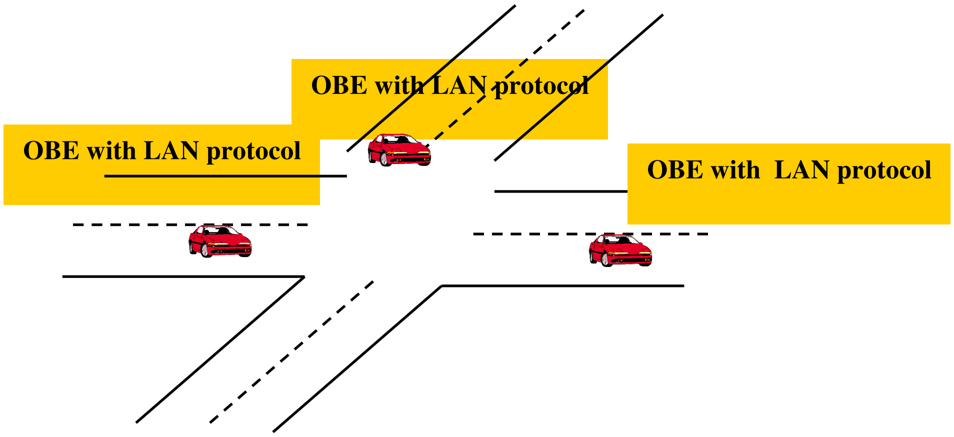

Figure 1. The Distributed Architecture

The Distributed Architecture aims to realize the networking service through the peer-to-peer interaction of wireless communication enabled vehicles alone. The PCIS architecture presupposes the existence of a roadside infrastructure.

Both the architectures are going to use some sort of radios. The car will be equipped with wireless on-board-emitter (OBE) while the infrastructure will have a wireless roadside-emitter (RSE).

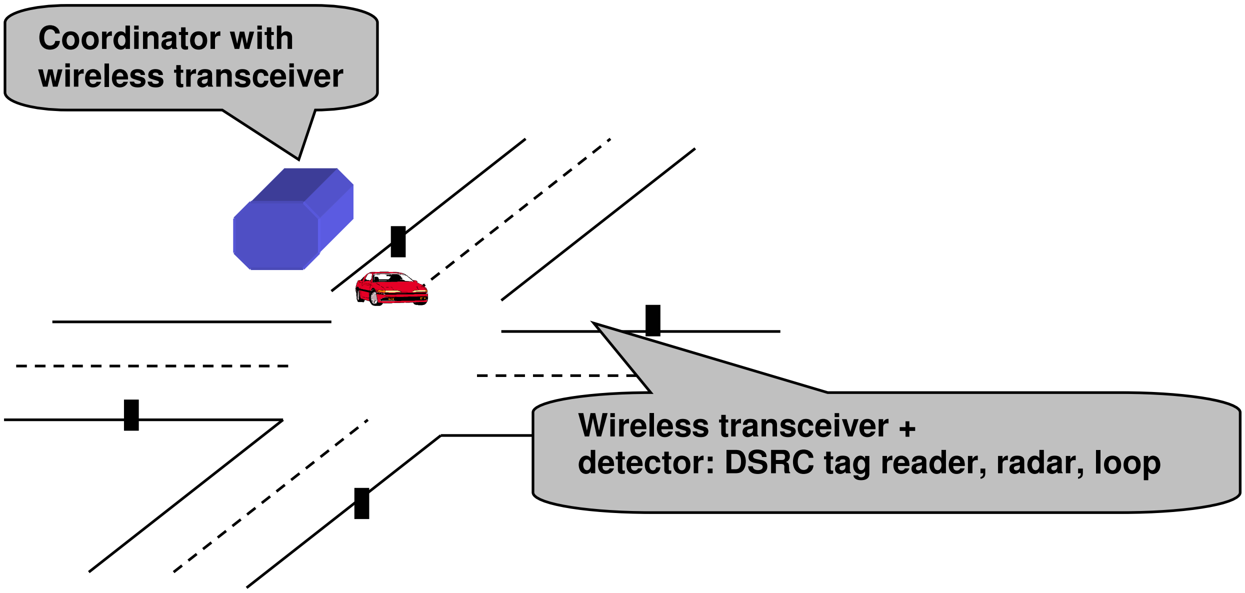

Figure 2. The Partially Centralized Infrastructure Supported Architecture

We are interested in the Distributed Architecture because it provides a degraded mode of operation in the event of failure of the roadside infrastructure. It may also enable large parts of rural America to enjoy IDS benefits without requiring the ubiquitous deployment of DSRC infrastructure across the nation.

Our interest in the PCIS architecture is due to the unpredictable evolution of the in-vehicle wireless market, the potentially greater operational benefits of partial centralization, and the possibility of public agencies mobilizing enough investment to drive at least a limited deployment of roadside DSRC infrastructure.

Both communication architectures are going to provide the two basic services we discussed at the beginning of this section: message delivery and neighborhood state map building.

In the distributed scenario the OBE equipped vehicles broadcast information about themselves and listen to the other vehicles . They fuse the information received via communication with the information gathered from the sensors.

In the infrastructure assisted scenario the vehicles behave in a similar way. While the vehicles send their messages the infrastructure listens and collects them. The infrastructure fuses the information in these messages with the information it gathers from its sensors (these are probably more precise than the ones that can be mounted in a vehicle). The infrastructure-enhanced map can then be broadcast back to the vehicles. At the same time the infrastructure may react to driver hazards or support their decisions.

In order to conduct enabling communications research, the first step is to select the radio technology we are going to use for the OBE and RSE.

Many different wireless radios are currently available on the market. Every one of them offers unique advantages and disadvantages. This report introduces a set of evaluation parameters and the group of the most promising wireless technologies available on the market. Using the evaluation parameters we will comparatively evaluate this group of technologies and, in the conclusion, we will suggest one technology as the platform for the development.

We are going to address the following research questions, in the following sections:

- What are the enabling technologies available for IDS?
- Which parameters should we consider to evaluate them?
- Given these parameters, which technology best fits the IDS application requirements and why?

# *1 Description of Available Technologies*

## 1.1 5.8 GHz DSSS / MC-DSSS

The idea of spread-spectrum radio transmission was proposed by the military who was seeking ways to prevent radio signals from being monitored or blocked by hostile parties. With direct-sequence spread spectrum (DSSS) the signal is passed through a spreading function and distributed over the entire band. DSSS avoids interference from conventional radio transmitters by configuring the spreading function in the receiver to concentrate the desired signal but spread out and dilutes interfering signals. Spread-spectrum radio is good at dodging interference from conventional sources – (signals that stay in one narrow area of the frequency band and don’t move), but its performance does not degrade gracefully with amount of interferences. When the interferences reach a saturation level the throughput suddenly drops to zero.

As described in [1-2], Direct-sequence spread spectrum (DSSS) radios combine data signal at the sending station with a higher data rate bit sequence, or chipping code, that divides the user data according to a spreading ratio. The chipping code is a redundant bit pattern for each bit that is transmitted, which increases the signal's resistance to interference. If one or more bits in the pattern are damaged during transmission, the original data can be recovered due to the redundancy of introduced by the chipping code. This radio sequence is used by many different systems (e.g. 802.11b, Bluetooth).

There are many DSSS radios available on the 5.8 GHz band, with different channel width, modulation schemes, ranges, and bandwidth (usually between 56 kbps, and 6.176 Mbps). In particular the Multi Code DSSS technology, described in [3], offers a 10 Mbps data rate and a 10 km range.

## 1.2 IEEE 802.11b

This standard uses the DSSS introduced in the previous section. It works in the FCC allocated 2.4 GHz – 2.4835 GHz band. Under 802.11b, devices communicate at a rate of 11 Mbps whenever possible. If signal strength or interference is disrupting data, the devices will drop back to 5.5 Mbps, then 2 Mbps and finally down to 1 Mbps. Though the radio may occasionally slow down, it keeps the network stable and reliable. 802.11b has a short range (1,000 ft / 305 m in open areas, 250 to 400 ft / 76 to 122 m in closed areas).

The 802.11b standard specifies a Complementary Code Keying (CCK), a set of 8-bit code word, which can be easily distinguished at the receiver side even with presence of substantial noise and multi-path interference, to decode all data sent over the air. These symbols encode 4 ?(5.5Mbps rate) or 8? (11 Mbps rate) and they are sent using QPSK to achieve a symbol rate of 1.375 Mbps. The data rate of 1 and 2 Mbps uses the original 802.11 DSSS techniques (Barker Sequence coding, BPSK/QPSK at 1MSps rate).

The performances degrade gracefully: thanks to dynamic rate shifting, the rate is dynamically adjusted to the background noise level.

## 1.3 CANOPY

The Motorola Canopy Wireless radio technology is currently used by Wireless Internet Service Provider (WIPS), to offer wireless connectivity. It operates in the unlicensed national information infrastructure (U-UNII) band, 5.25 to 5.35 GHz and 5.725 to 5.825 GHz, but it can be adapted to work on the 5.85-5.925 GHz band, reserved to ITS applications. The Medium Access Control method is Time Division Duplex / Time Division Multiple Access (TDD/TDMA). The modulation type is high index BFSK, optimized for interference rejection. Motorola claims that, because of this modulation scheme, the signal to interference ratio can be kept under 3dB. The range goes up to 2 miles in the 5.2GHz band and up to 10 miles in the 5.79 GHz band. The transmit power meets the regulation of the FCC U-NII bands (< 43 dBm).

## 1.4 Bluetooth

Bluetooth [9] is a new wireless technology, which operates in the 2.4 GHz ISM (Industrial Scientific Medicine) band. It is designed to replace wired connectivity between different personal electronics (e.g. connectivity between personal computer and printer, personal computer and digital camera and so on). It provides Omni-directional connectivity between devices, and supports point to point and point to multi points connections.

Wireless technologies like IrDA has been deployed for numbers of years, but they didn't gain users' popularity because of their "line of sight" communication, and their point to point connection. When Bluetooth-capable devices come within range of one another, they start discovering each other, and try to offer services to each other. Users do not need to establish and maintain devices connection. Devices within the communication range form a personal-area network (PAN) or piconet.

To minimize power consumption of devices, the Bluetooth standard limits devices communication range to be within 10 meters. To minimize interfaces from other piconets, Bluetooth subdivides the spectrum into 79 channels and uses a modulation technique called spread-spectrum frequency hopping. In this technique, a device randomly chooses frequencies within a designated range, and switches from one channel to another on regular basis. In the case of Bluetooth, the transmitters change frequencies 1,600 times per sec. Thus it is unlikely that two devices use same channel at the same time, and even they do, the interference lasts only for a tiny fraction of a second.

## 1.5 DSRC

Recently the spectrum from 5.850 to 5.925 GHz (5.9 GHz) has been allocated in the United States “to enhance the safety and the productivity of the transportation system”[12]. ASTM (American Society for Testing and Materials) standardization committee E17.51 is working on the development of the standard of 5.9 GHz **DSRC** (Dedicated Short Range Communication). DSRC is a short to medium range communication service that supports both Public Safety and Private operations in roadside to vehicle and vehicle-to-vehicle communication environments. DSRC is meant to be a complement to cellular communications by providing very high data transfer rates in circumstances where minimizing latency in the communication link and isolating relatively small communication zones are important.

Preliminary standard proposes max data rate up to 27 MB/s with 7 licensed channels, and up to 1000 meters transmission range.

## 1.6 802.11a

The Institute of Electrical and Electronics Engineering (IEEE) has developed 802.11a standard for the next generation of enterprise-class wireless LANs. It offers greater scalability, better interference immunity and significantly higher data rate than 802.11b. 802.11a has the same MAC (Media Access Control) layer and similar communication range as 802.11b.

The 802.11a operates in the 5GHz Unlicensed National Information Infrastructure (U-NII) band, which is not as highly populated as the 2.4 GHz band of 802.11b. Therefore, it has lower external interference than 802.11b. Moreover, Forward Error Correction (FEC) was added to the 802.11a specification to improve the reliability and utilization of the channel, which reduces amount of retransmissions due to data loss.

To offer much higher data rate, 802.11a uses Orthogonal Frequency Division Multiplexing (OFDM) modulation scheme. 802.11a standard subdivides the spectrum into 8 non-overlapping 20 MHz wide channels. Each channels is again subdivided into 52 subcarriers with each subcarriers being approximately 300 KHz wide. OFDM allows transmitters and receivers to send and receive multiple data symbols on different subcarriers in parallel. This significantly increases the amount of information that can be communicated n unit time.

As stated in [10] the 802.11a operates in the 5GHz U-NII band. In United State, frequency operational ranges are 5.15 - 5.25 GHz, 5.25 - 5.35 GHz and 5.725 - 5.825 GHz. The Standard subdivides the spectrums into 8 non-overlapping channel with 52 subcarriers each. It uses OFDM for its modulation scheme. It has maximum data rate up to 54 Mbps. It has communication range up 10,000 ft.

### 1.7 802.11g

The Institute of Electrical and Electronics Engineering (IEEE) 802.11g standard committee is currently finalizing the standard. Consumers now can purchase pre-standard 802.11g wireless cards in stores, and companies claim that they can easily convert these cards to the finalized standard by updating the firmware. 802.11g is designed to operate at the same spectrums as 802.11b, but offers as much higher data rate than 802.11a.

802.11g is backward compatible with existing 802.11b, and they will be able to operate concurrently with each other at the same regions. 802.11g has the same modulation scheme as 802.11b (?). In addition, it has adapted OFDM modulation from 802.11a, which allows it to achieve maximum throughput of 54Mb/s. Some test results have shown that, in static environment, 802.11g offers better data rate and coverage area than any existing Wavelan technologies [11]. However, 802.11g has the same limited amount of channels as 802.11b, so it is not as scalable as 802.11a which offers more than twice amount of channels.

802.11g operates in the 2.4GHz ISM band. The 2.40GHz to 2.483GHz bandwidth are divided into three non-overlapping channels. It has communication range up 10,000 ft.

## *Evaluation Parameters*

There are many available radio technologies with really distinct performances. In this section we are going to describe the evaluation parameters we are going to use to select a particular radio technology.

The evaluation parameters are selected based upon the IDS application requirements.

One of the first evaluation parameters is **range**. The IDS application needs to start to track a vehicle when this vehicle is approaching the intersection. It is important that the range of the radio is not too small; otherwise the IDS application will not have enough time to gather data, perform computations and issue a warning. It is not good to have a too large range as well because in this case an intersection may be interfered by vehicles at neighboring intersections. We can filter out this information, but it takes computing resources (for the filtering) and communication bandwidth. The range is directly proportional to the number of vehicles that are able to communicate with the infrastructure. For this reason the range is inverse proportional to the radio performances (i.e. big range => channel congestion => bad radio performance). The range choice is going to be based finally on the IDS application requirement, that has not been determined yet. Approximately, this range is going to be between 3,000 and 6,000 ft.

Another important evaluation parameter is **reliability**. Since the communication is going to deliver warnings, reliability is important. While we are listening via Internet to a broadcast radio it is not a big deal if we lose 1 ms of music. Human ears cannot even tell that there has been an interruption. On the contrary, we cannot tolerate to lose a safety critical warning. A value of $10^{-6}$ bit error rate should be enough (a higher reliability would be even better). In [5], prof. Sengupta introduced the interesting concept of variable reliability. His proposal is to guarantee a higher reliability to important messages (e.g. a warning message) and lower reliability to less important (e.g. the sensor reading of a vehicle at the border of the IDS application tracking zone).

Another evaluation parameter is **latency (or delay)**. A safety message is useful only for a short time. Large delay make cause the vehicle unable to respond in time for the hazard. Thus safety messages have to be delivered with a bound on delay . Different radio technologies offer different bounds on latency. The maximum tolerable latency depends on the application itself. Even if this requirement has not being stated yet, it should be in the order of 10 ms. In [5] the concept of latency and reliability are bound together in an interesting way.

The last parameter we are going to consider is **data rate**. The radio needs to offer a bandwidth big enough to support the communication protocol we are developing (that will be described in the report due June 2003). Every vehicle and the infrastructure need to be able to communicate in a given time even in congested situation. Based upon the preliminary sketches of the algorithm we are developing, on [6-7] and on some mathematical and statistical modeling [8] it seems that a 1Mbps data rate is required and a higher rate is recommended.

Given a particular environment it is important that the radio technology has a good **multi-path resistance**. The vehicles reflect the wireless signals and the radio receives the same signal many times with time shift and decreasing amplitude. The direct and reflected signals interfere with each other, making harder the successful reception of the original signal. The situation is worsened by the fact that the direct signal (most powerful) is often blocked by a string of vehicles between the sender and the receiver. Some radio technologies have introduced new techniques to deal with the problem, but some not. It is important for our choice, to select a technology with a high resistance to multi-path.

Last but not least, we are going to consider **interference likelihood** of the spectrum. The radio spectrum is dramatically congested. Many part of it are shared by many applications and standards. Even if a radio technology has a good range, is reliable, has a bound on the maximum latency and a high bandwidth it may not be usable because the part of the spectrum it uses may be congested. The interference likelihood should be small today as well as in the future. We do not want to deploy our application on a part of the spectrum that is almost unused today but it is going to be so crowded 5 years from now that our application will not be able to work.

We did consider other parameters such as the **size** of the device, the **power consumption** and the **antenna** requirements that are of critical importance on the vehicle side of the application. We are not going to list them in our evaluation in the next section because all the technologies we considered meet these requirements.

# 3 Technology Evaluation and conclusions

We select an out-of-the-shelf wireless technologies and we evaluate them following the criteria described in section 2. The results are summarized in table 3.1.

| Radio technology | Range | Reliability | Latency | Data Rate | Interference likelihood | MP resistance |
|---|---|---|---|---|---|---|
| 5.8 GHZ DSSS | > 10,000 | $10^{-6}$ | ? | 10 | HIGH | GOOD |
| 802.11b | > 3,200 | $10^{-6}$ | ? | 11 | HIGH | GOOD |
| CANOPY | > 10,000 | $10^{-6}$ | ? | 10 | HIGH | GOOD |
| Bluetooth | 30 | $10^{-5}$ | ? | 1 | LOW | BAD |
| 802.11a | > 10,000 | $10^{-6}$ | ? | Up to 54 | HIGH | GOOD |
| 802.11g | ? | ? | ? | ? | HIGH | GOOD |
| DSRC | > 10,000 | $10^{-6}$ | ! | Up to 27 | NULL | GOOD |

Table 3.1: evaluation results

[REMINDER Latency = there are no guarantees on the maximum latency, but there is plenty of statistical analysis. Find out what is the value and fill it here]

As we wrote in the previous section, the IDS application requirement on range has not been finalized yet, but almost all technologies fall in the interval that we have specified. The only exceptions are Bluetooth, whose short range makes it completely unsuitable, and 802.11b, that may not meet the finalized requirements.

As far as reliability and multi path resistance are concerned, all the alternatives but Bluetooth, have an error rate smaller or equal to the selected one and a good resistance to multipath.

Bandwidth is not a concern, all the radios offer at least 1 Mbps. 802.11a and DSRC seem to be preferable because of the higher bandwidth:

The only parameter where the technologies differentiate themselves is the interference likelihood. The only two technologies with acceptably low interference likelihood are Bluetooth and DSRC. However Bluetooth cannot be used because of its short range, low reliability and poor multipath resistance. DSRC is going to work on a part of the spectrum licensed specifically for transportation safety applications, so interferences are going to be minimal.

Because of its high bandwidth, small error rate, and strong resistance to multipath, DSRC seems to be the ideal candidate for a wireless technology for IDS applications. However the DSRC standard is not completed yet and it is currently impossible to use this platform.

The DSRC standard follows closely the 802.11a standard. It should then be easy to migrate a system working with 802.11a radios to DSRC radios when they will be available.

We recommend to develop the IDS system on top of 802.11a radios, because they have small bit error rate, correct range, really high data rate, good resistance to multipath and high compatibility with the soon to be available DSRC radios. We suggested switching to DSRC radios as soon as it is possible.

References

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