Wireless Technology Assessment for Automotive Applications

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ABSTRACT

Recently, automotive safety applications with wireless communications have been the focus of worldwide research and development. DSRC (Direct Short Range Communications) in particular, with its low latency vehicle-to-vehicle connectivity, now appears to be a promising wireless technology for time-sensitive crash avoidance applications. IEEE 802 and other standards organizations are advancing international wireless standards, most prominent being IEEE 802.11 and 3GPP (3rd Generation Partnership Project) LTE (Long Term Evolution). IEEE 802.11 (a.k.a. Wi-Fi) based client and access point devices serve a variety of home, office and outdoor applications, which include the 802.11p based DSRC radio. Both 802.11 and LTE deployments are accelerating worldwide, bringing about volume pricing and fast advancing technological capabilities. In this paper, we first examine major automotive applications, including emerging applications, and then discuss wireless technologies and standards best suited to support these applications.

KEYWORDS

Wireless communication, DSRC (Dedicated Short Range Communication), IEEE 802, IEEE 802.11p, mobile wireless communication, 4G, LTE, radio channel emulator

MOTIVATION

For many years now, wireless vehicle communication has been used for emergency calling, concierge services, remote diagnostics and other automotive applications. As new wireless technologies emerge, new automotive applications are being considered. Recently with the fast advancements in wireless connectivity, more time-sensitive and mission-critical automotive safety applications have become feasible and are currently under development. And as the number of wireless technologies grows, the choice of the appropriate technologies for a variety of automotive applications has to be carefully considered.

We summarize automotive applications and the preferred specification in ***Table I***. In the middle column of ***Table I***, black fonts show existing applications and blue fonts show new or emerging applications [1] [2] [3] [4] [5]. First we categorise various applications into 7 groups: "Crash avoidance with high vehicle speed", "Crash avoidance with low vehicle speed", "Safety awareness", "Emergency", "Eco/Green/Mobility with vehicle speed", "Eco/Green/Mobility without vehicle speed" and "Convenience". The right column of ***Table I*** shows the preferred specifications for each application group. Specifications that strongly preferred are underlined. Generally, safety or emergency applications require "High reliability" and "Low error rate". Some safety or emergency applications also require "Low communication latency" or "Communication during high vehicle speed. On the other hand, "Convenience" applications benefit from "High data transmission rate" or "Communication stability".

Group	Applications	Preferred Specifications
Crash Avoidance-I (High Speed)	1. Emergency Electronic Brake Light 2. Forward Collision Warning 3. Blind Spot Warning /Lane Change Warning 4. Do Not Pass Warning 5. Left Turn Assist	<u>Low error rate</u> <u>High reliability (up-time)</u> <u>Low latency</u> [Max 100ms] <u>High vehicle speed</u> [80mph] Minimum radio interference Robust with obstructions in comm. path Medium comm. range [Max 100m]
Crash Avoidance-II (Low Speed)	6. Intersection Movement Assist	<u>Low error rate</u> <u>High reliability (up-time)</u> <u>Low latency</u> [Max 100ms] Medium vehicle speed [60mph] Minimum radio interference Robust with obstructions in comm. path Short communication range [10–100m]
Safety Awareness	7. Remote Diagnosis (EV Battery Monitoring) 8.Stopped Vehicle (or Pedestrian) Warning 9. Road Condition Warning	<u>High reliability (up-time)</u> Medium latency [0.5 – 1s] <u>High vehicle speed</u> [80mph] Minimum radio interference Robust with obstructions in comm. path <u>Long communication range</u> [100–1000m]
Emergency	10. Emergency Response (e-Call)	<u>Low error rate</u> <u>High reliability (up-time)</u> <u>High vehicle speed</u> [80mph] Minimum radio interference Robust with obstructions in comm. path <u>Long communication range</u> [1– 100km]

Group	Applications	Preferred Specifications
Eco / Green / Mobility w/ Vehicle speed	11. Electric Payment (Toll Application)* 12. Probe (Traffic Data) Collection* 13. Eco-Lane (ACC w/Eco Speed) 14. Green Wave (w/Traffic Signal Timing) 15. Traffic Signal Timing	Low error rate High reliability (up-time) High vehicle speed [80mph] Minimum radio interference Robust with obstructions in comm. Path Communication range [100m]
Eco / Green / Mobility General	16. Traffic Signal Timing (for Idling Stop)	Low vehicle speed [20mph] Minimum radio interference Strong for obstacles in comm. Path Communication range [50m]
Convenience	17. Charging Station Guidance / Info. (for EV) 18. Mobile-commerce / Mobile-advertisement 19. Web browsing 20. File (Video, Audio) downloading 21. Videophony	High data transmission rate*** High vehicle speed**** Stability**** Security**** Privacy****

*: 11. & 12. needs "Security" and "Privacy"

**: Only 12. needs long communication range [1-10km]

***: Web browsing [10kb/s – 1.5Mb/s] , Videophony [128 kb/s – 10Mb/s]

****: Depend on usages

Table I: Major automotive applications [1] [2] [3] [4] [5]

802.11 WIRELESS STANDARDS

With its low transmission latency between neighbouring vehicles, the 802.11p based DSRC technology is optimized for time-sensitive crash avoidance applications [1]. IEEE 802.11s (mesh networking) is also feasible for ad-hoc and multi-hop communications, but it has not yet been applied to automotive applications and existing implementations of 802.11s may need some work before they can handle high speed vehicular networking [6]. The IEEE 802.11 Working Group is developing many new wireless standards [7]. ***Table II*** shows these emerging standards. 802.11ai (fast link) targets fast initialization (i.e. fast network connection) for fast moving terminals. Using wider channels and more efficient modulation, 802.11ac (Very High Throughput Wi-Fi) features higher transmission rate in same spectrum as the commercialized 802.11n. 802.11ah (Sub 1 GHz) is characterized by its long transmission range (over 1 km).

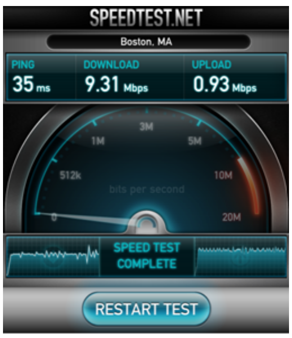
Standard	Overview	Specification			Standard completion (Target)
		Transmission rate	Communication range	User velocity	
11aa	*Video Transport Streams*	*Robust streaming of AV transport streams*			Jun/12
11ac	*High Throughput w/ wider channels*	Up to 6.9 Gbps			Dec/13
11ad	*High Throughput in 60 GHz band*	Up to 6.8 Gbps	10 m at 1 Gbps		Dec/12
11af	*Wi-Fi on TV White Space*	802.11n/ac rates scaled to channel	Up to 5 km		Dec/13
11ah	*Sub 1 GHz*	> 100 kbps	1 km		Mar/15
11ai	*Wi-Fi for mobile*	*Fast initialization (target 100 ms)*		Target: + 200 km/h	Mar/14

Table II: New 802.11 Wireless technologies [7]

MOBILE COMMUNICATION – LTE

Field Performance Measurements

The US government supports the early deployment of 4th-generation mobile communications, such as LTE deployment in the US nationwide [8] [9]. LTE has high theoretical performance (uplink data transmission rate: 86 Mbps, downlink data transmission rate: 326 Mbps) and is well suited for almost all of the automotive applications [10]. Even in our field measurements, we measured very high performance (uplink data transmission rate: 3-8 Mbps, downlink data transmission rate: 10-30Mbps, communication latency: approximately 100ms) that satisfies the requirements of almost all of automotive applications. ***Figure I(a)*** shows the control panel of speedtest.net, the throughput measurement tool we used. ***Figure I(b)*** shows sample measurement data. Measurement conditions are described in ***REFERENCE [11]***.



(a) Measurement tool

Date	ConnType	Lat	Lon	Download (kbps)	Upload (kbps)	Latency (msec)	ServerName
10/2/2011 11:10	Lte	42.41827	-71.6034	19518	4920	98	Boston, MA
10/2/2011 11:10	Lte	42.41827	-71.6034	19518	3983	106	Boston, MA
10/2/2011 11:09	Lte	42.41827	-71.6034	17300	2772	96	Boston, MA
10/2/2011 10:55	Lte	42.28415	-71.6087	11467	309	98	Boston, MA
10/2/2011 10:55	Lte	42.28415	-71.6087	35694	6542	96	Boston, MA
10/2/2011 10:54	Lte	42.28415	-71.6087	31827	7324	97	Boston, MA
10/2/2011 10:53	Lte	42.28415	-71.6087	21281	7423	90	Boston, MA
10/2/2011 10:53	Lte	42.28415	-71.6087	9455	6937	90	Boston, MA
10/2/2011 10:52	Lte	42.28415	-71.6087	18291	4633	94	Boston, MA
10/2/2011 10:37	Lte	42.28415	-71.6087	14298	989	94	Boston, MA
10/2/2011 10:36	Lte	42.28415	-71.6087	41880	7882	92	Boston, MA
10/2/2011 10:36	Lte	42.28415	-71.6087	34324	7346	92	Boston, MA

(b) Sample measured data

Figure I: LTE performance field-measurements [11] [12]

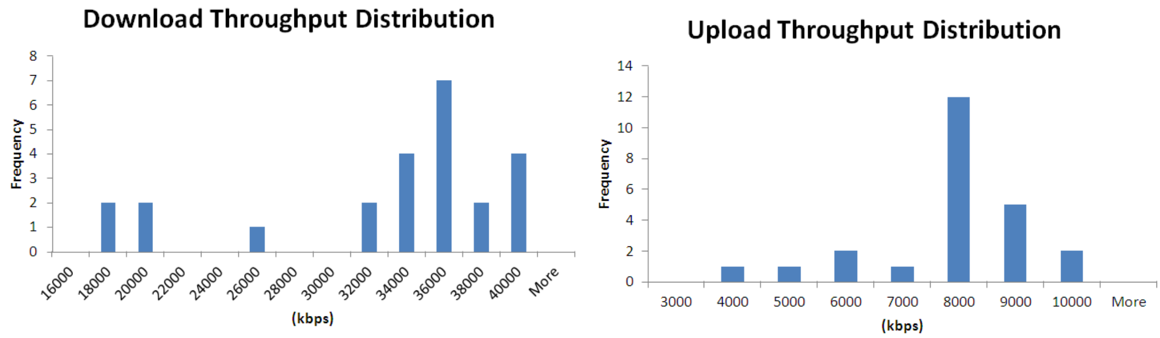


Figure II: LTE performance while driving at 60mph [11] [12]

Location in the car	DL (kbps)	UL (kbps)	Latency (ms)
Inside center of the car	14800	5499	112
Inside driver front window	14527	8824	107
Inside passenger front window	13687	8001	111
Outside the car	19703	8587	112

Table III: LTE performance inside and outside of the vehicle [11] [12]

Even while driving at 60 miles-per-hour with open space (rural highway) conditions, LTE shows high performance (downlink data transmission rate: 18-40 Mbps, mode = 36 Mbps), (uplink data transmission rate: 4-10 Mbps, mode = 8 Mbps) (***Figure II***). We also measured the LTE performance at various locations in a vehicle while using a tablet device (without additional antennas). For this measurement the car was parked (***Table III***). As you can see in ***Table III***, downlink data transmission rate decreases 25-30% from the outside of the vehicle to the inside of the vehicle, but uplink data transmission rate and communication latency do not change vs. location.

Performance Improvement Approaches

Actual LTE performance varies based on the number of mobile terminals per base station and on the bandwidth of the backhaul network that connects the base stations to the carrier's core network. Internet connections are made via the core network.

New base station architectures are emerging to address the performance and throughput requirements of wireless broadband networks. One approach is to deploy small base stations with limited coverage (i.e. small cells). Interconnecting such small base stations to the core network has to be done economically. Laying cabling to connect each small base station is deemed too expensive. Thus, while traditional Macro base stations are typically backhauled using fiber optic or copper cabling, the new generation of small base stations are being backhauled via microwave links, including 802.11a/n links, which serve to avoid the expense of cabling each new base station. So, base stations can now connect mobile devices to the Internet using cabled connections, Wi-Fi or other microwave links (***Figure III***). Wireless backhaul enables the deployment of small base stations, allowing wireless networks to support more users with better performance by virtue of reducing the number of users per base station [13].

Wired backhaul connections, such as optical fiber or copper lines provide higher data transmission rate, but wireless backhaul connections cost less to deploy. In response to the small base station trend, the FCC is working to ease regulatory restrictions on microwave point-to-point links used for backhauling, making more spectrum available for microwave backhaul and thus facilitating the deployment of small base stations in order to increase wireless coverage and capacity. ***Figure IV*** shows an example of line-of-sight wireless backhaul connectivity using building roof tops [14].

While comparatively low cost and fast to deploy, small cell architecture has 2 issues. The first issue is hand-off (mobile terminal's transition from one cell to another). Frequent hand-offs that occur as wireless devices move among numerous small cells mixed with fewer Macro cells cause communication latency, packet loss and dropped sessions. The second issue is radio interference that typically occurs at the edges of the cells in the overlapping regions of coverage, where mobile stations are within reach of more than one base station. This cell-edge interference can disrupt wireless connectivity and cause 'confusion' as to which base stations should cover which mobile stations in the overlapping regions. The trend towards smaller cells aggravates this issue and introduces the need for base station synchronization and coordination to better manage the overlapping regions.

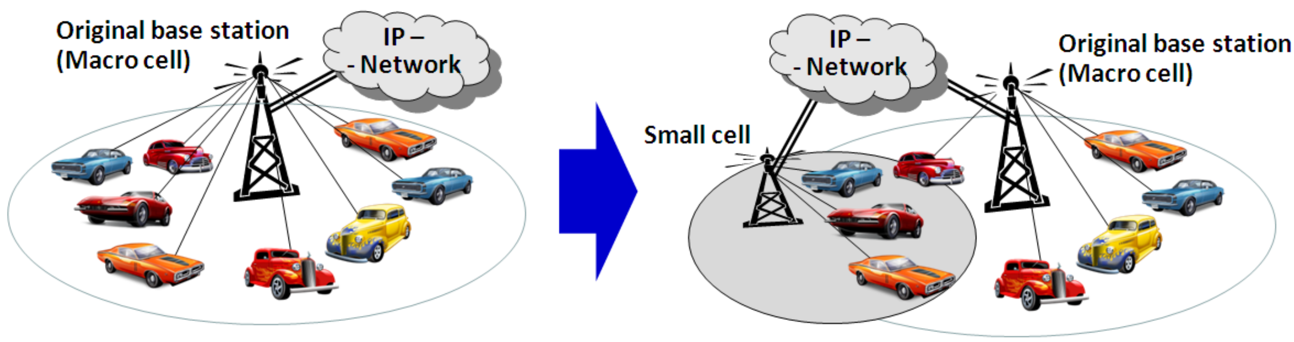


Figure III: Small cell deployment (concept)

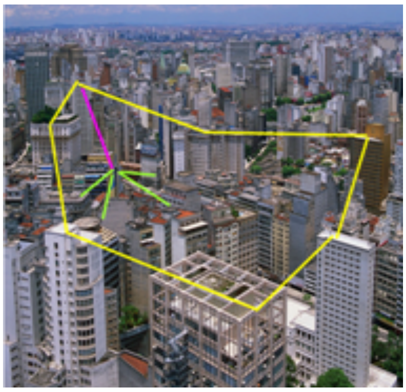


Figure IV: Line-of-sight wireless backhaul example
(using building roof tops**)** [14]

ASSESSMENT with SPECIFICATIONS

Table IV shows wireless technology candidates for automotive applications. In the right column, black fonts show existing wireless technologies and blue fonts show emerging wireless technologies. DSRC (802.11p) is the most suitable technology for time-sensitive automotive applications requiring low communication latency and high reliability (1-6, 13-16 and 18 of ***Table IV***).

LTE offers advantages with market-ready infrastructure and terminals, but currently lacks QoS (Quality of Service), which may be problematic due to potential data traffic congestion in the LTE IP core network [16] [17]. Presently, LTE can be used for non-time-sensitive applications including safety applications (all of applications of ***Table IV***, except 1-5 and 11). In the future, to better handle mission-critical real-time traffic, carriers are planning to deploy the IMS (IP Multimedia Subsystem) protocol to run over LTE. IMS defines 9 levels of priority to help regulate the traffic flow over the LTE network, allowing safety or emergency related messages to be transported with the lowest latency and highest reliability [15].

General purpose Wi-Fi networks are suitable for convenience application (19-21 of ***Table IV***) and can be used when vehicles are at rest stops, parked near Internet cafes or at other places where Wi-Fi access points are deployed. In the future, 802.11ai (quick link) is expected to be used for electronic payments and mobile-commerce / mobile-advertisement applications (11 and 18 of ***Table IV***).

Categories	Applications	Candidates Technologies
Crash - High Speed	1. Emergency Electronic Brake Light 2. Forward Collision Warning 3. Blind Spot Warning / Lane Change Warning 4. Do Not Pass Warning 5. Left Turn Assist	802.11p 802.11s also may be a candidate.
Crash - Low Speed	6. Intersection Movement Assist	802.11p, 802.11s LTE may be a candidate.
Safety Awareness	7. Remote Diagnosis (EV Battery Monitoring)	LTE, (If roadside units are deployed, WiFi is a candidate.)
	8.Stopped Vehicle (or Pedestrian) Warning	802.11p, LTE
	9. Road Condition Warning	LTE, Satellite communication
Emergency	10. Emergency Response (e-Call)	2G/3G, Satellite communication (PSAP improvement, i.e. NG-911 is required for LTE.)

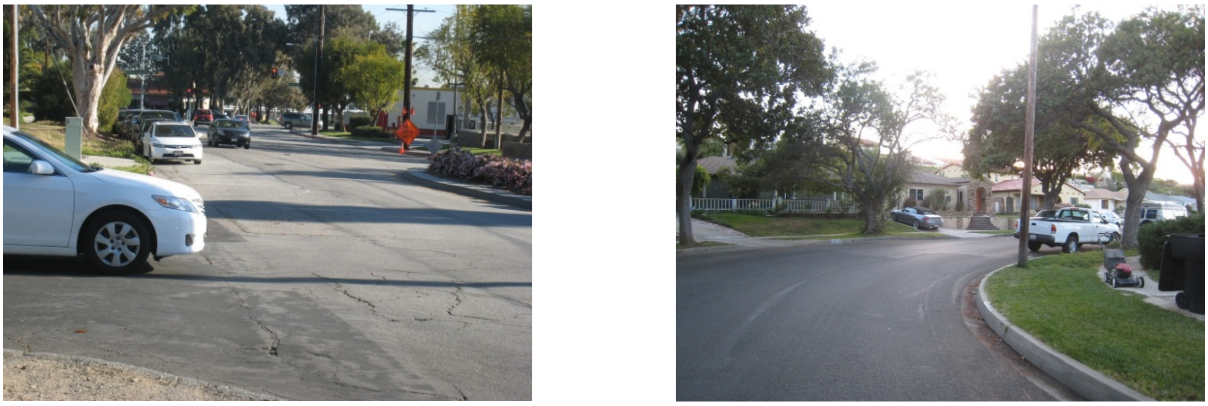
Categories	Applications	Candidates Technologies
Eco / Green / Mobility w/ Vehicle speed	11. Electric Payment (Toll Application)	Current Transponder, 802.11p (Future 802.11ai may be a candidate.)
	12. Probe (Traffic Data) Collection	LTE, Satellite communication
	13. Eco-Lane (ACC w/Eco Speed) 14. Green Wave (w/Traffic Signal Timing)	802.11p (LTE may be usable for stable conditions.)
	15. Traffic Signal Timing	802.11p, LTE (802.11s also may be a candidate.)
Eco / Green / Mobility General	16. Traffic Signal Timing (for Idling Stop)	802.11p, LTE, 802.11s
Convenience	17. Charging Station Guidance/ Info. (for EV)	LTE, Satellite communication (future 802.11ah)
	18. Mobile-commerce / Mobile-advertisement	802.11p, LTE, (future 802.11ai)
	19. Web browsing 20. File (Video, Audio) downloading 21. Videophony	LTE for driving conditions, Wi-Fi for parking conditions (Future 802.11ac is a candidate for parking conditions.)

Table IV: Wireless technology candidates for automotive applications

ASSESSMENT with RADIO EMULATOR – NEXT STEP

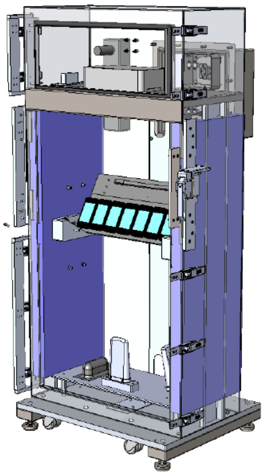
In previous sections, we examined wireless technologies and their specifications (including field measurements). But when making a final selection of radio technology, we have to consider many factors in the real world, such as how well the technology handles challenging radio propagation environment, radio interference, multipath, fading, effect of Doppler and other wireless signal impairments. For example, crash avoidance application at crossings or curves with bad visibility (see ***Figure V***) requires robust radio propagation even in the presence of signal obstructions in the communication path. For this reason, in Japan, 700MHz instead of 5.9GHz wireless spectrum is being considered for crash avoidance applications of DSRC [16].

Figure VI shows an example of the test equipment typically used to emulate wireless propagation conditions. We can emulate typical radio signal impairments present on the road, for example multipath, Doppler fading, interference and other impairments, in a controlled RF environment chamber (***Figure VI***). In the chamber, we isolate the radio under test from the outside interference and then use channel emulation technology to emulate real-life radio environment on the road (see ***Figure VII***). As our next step, we plan to conduct deeper wireless technology assessments by reproducing real world conditions in a laboratory, using such measurement equipment [19].



(a) **(b)**

Figure V: Samples - Crossing or curves with bad visibility



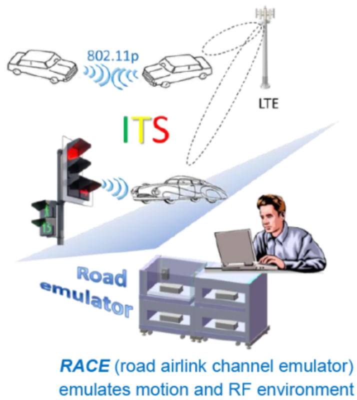


Figure VI: Radio environment emulator

Figure VII: Radio environment emulation (concept)

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