AN OVERVIEW OF SDR OPPORTUNITIES AND CHALLENGES IN TELEMATICS

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ABSTRACT

Since the first introduction of a combined telecommunications and informatics platform, known as telematics, into automobiles more wireless and location technologies have been integrated into automobiles. Original Equipment Manufacturers (OEMs) are faced with new technical and integration challenges as a result of automobiles becoming farms of wireless technologies. In addition, OEMs are under the pressure to reduce telematics products cost and time-to-market in order to stay competitive. Therefore, the demand for concepts like Software Defined Radio (SDR) is growing. SDR has the potential to realize flexible, multi-band, multi-standard embedded telematics products that can be reprogrammed over the air. This paper provides an overview of the automotive telematics market, services, and key hardware functional blocks. SDR opportunities, challenges, tiers, and main blocks in telematics are addressed as well.

I. INTRODUCTION

The demand for the integration of several wireless and location technologies into the same product has been increasing since the first introduction of telematics into automobiles around the mid 1990's. These technologies include cellular, Personal Communication Systems (PCS), Digital Communication Systems (DCS), Global Positioning Systems (GPS), Bluetooth, Local Area Networks (LAN), Satellite Digital Audio Radio Systems (SDARS), Analog Modulation (AM), Frequency Modulation (FM), and Digital Audio Broadcast (DAB). More technologies are expected to be integrated into automotive telematics in the near future such as Dedicated Short Range Communications (DSRC) and Ultra Wideband (UWB). OEMs are faced with new technical and integration challenges as a result of integrating several wireless technologies into automobiles. In addition, OEMs are under the pressure to reduce telematics products cost and time-to-market in order to stay competitive. Therefore, the demand for concepts like SDR is growing. SDR has the potential to realize cost-effective, reprogrammable, multi-band, multi-standard telematics products with reduced development cycles.

There are several publications that address SDR opportunities and challenges in the defense and wireless industries. However, there is a lack of publications that discuss SDR opportunities and challenges in the telematics industry. The contributions of this paper are: (1) to provide an overview of telematics market, services, technologies and products, (2) provide an overview of SDR challenges, benefits, tiers, and main blocks in telematics.

The paper is organized as follows. Section II provides an overview of telematics. Section III provides an overview of SDR challenges, benefits, tiers, and key blocks in telematics. Conclusions are provides in section IV.

II. TELEMATICS OVERVIEW

Telematics is defined as the integration of telecommunications, location and information technologies into automobiles. There is no doubt that telematics is becoming one of the key differentiators for the automotive industry, [1-7]. According to ABI Research the telematics commercial global market is expected to grow from $2.5 Billion in 2004 to $7 Billion in 2010, [3]. Telematics services include roadside assistance, airbag deployment notification, routing assistance, convenience services, emergency assistance, stolen automobile tracking, remote door unlock and remote automobile diagnostics, [3]. Customer demand for telematics services is increasing as shown in Table I, [3, and 7]. Table I shows the average calls received by OnStar, Incorporated in two time periods. OnStar, Incorporated is a leading telematics service provider in North America.

Table I: Average calls for key telematics services.

Service	Average calls (October to December 2003)	Average calls (May to July 2005)	Delta
Airbag Notification	800	900	+12.5%
Emergency calls	8000	15000	+87.5%
Remote Diagnostics	20000	27000	35%

A telematics platform consists of the following key functional blocks: (1) location device, (2) communications device, (3) broadcast device, and (4) vehicle interface, [8].

A. Location Device

The location device provides automobile position for all location-based services. The core component of the location device is a GPS receiver. The integration of GPS receivers into telematics products has been accelerated due to the Federal Communication Commission (FCC) mandate that mobile phones be able to provide the location of an E-911 call in the United States [8]. Similar legislations are taking place in Europe. The GPS receiver provides position, velocity and time (PVT) solution to the telematics applications. The PVT solution is combined with speed from the vehicle bus and heading from obtained form a gyro to enhance GPS availability and accuracy in navigation services.

The GPS receiver is connected to an active GPS antenna via RF cables. A typical GPS antenna used in telematics applications consists of the three primary elements as shown in Fig. 1. The antenna's radiating element is a right hand circularly polarized (RHCP) patch tuned to receive GPS signals at the L1 carrier frequency (1575.42 MHz). The received signal is fed to a low-noise amplifier (LNA). After amplification, the signal is filtered around the L1 carrier frequency. The filtered signal is then delivered to a GPS receiver through an RF cable. The GPS receiver provides a DC bias voltage required to power the LNA through the RF cable.

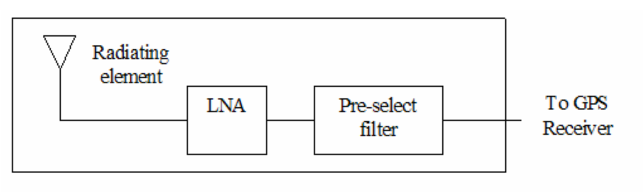

Fig. 1. Block diagram of a typical GPS antenna used in telematics.

The initial task of the GPS receiver is to down-convert the GPS signal to a frequency that is computationally feasible for the hardware to perform the analog-to-digital conversion and signal processing tasks. The down conversion process typically involves multiple stages prior to reaching the final baseband frequency. A typical GPS receiver front end is shown in Fig. 2. The frequency translation and mixing process are mathematically described in (1) – (6), [9]. The IF signal is then processed using a general purpose processor (GPP) or a digital signal processor (DSP).

A simplified version of the received GPS signal at the input of the GPS receiver is represented in (1).

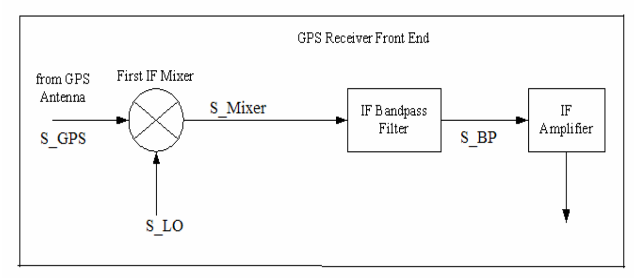

Fig. 2. Front-end functional diagram of a GPS receiver.

$$S\_GPS = A\cos(2\pi f_{GPS} t) \qquad (1)$$

The local oscillator signal is represented in (2).

$$S\_LO = A\cos(2\pi f_{LO} t) \qquad (2)$$

The mixing process produces a new signal that contains two frequency components as described in (3).

$$S\_Mixer = 0.5A\{\cos[2\pi(f_{GPS} - f_{LO})t] + \cos[2\pi(f_{GPS} + f_{LO})t]\} \qquad (3)$$

A band pass filter is then used to reject the second term in (3). The filtered signal at the output of the initial intermediate frequency (IF) stage is represented in (4).

$$S\_BP = 0.5A\cos[2\pi(f_{GPS} - f_{LO})t] \qquad (4)$$

The difference between the received GPS signal frequency and the local oscillator frequency is referred to as the intermediate frequency as depicted in (5).

$$f_{IF} = |f_{GPS} - f_{LO}| \qquad (5)$$

Every GPS receiver has an image frequency that is equal to the sum of the local oscillator and the intermediate frequency as illustrated in (6).

$$f_{IMAGE} = f_{LO} + |f_{GPS} - f_{LO}| \qquad (6)$$

The image frequency is rejected by the band pass filter in the GPS antenna so that it does not cause interference to the desired signal.

B. Communication Device

The communication device provides two way communications between the automobile and the outside world or between devices inside or in close proximity of the automobile in the case of personal area networks (PAN) technologies. Wireless communication systems are classified into the following types based on their coverage range (see Fig. 3): (1) PAN systems is used for short range data communications, (2) local area networks (LAN) are used for data communications between the automobile and hot spots, (3) metropolitan area networks (MAN) provide broadband data communications between the automobile and the outside world, (4) wide area networks (WAN) provide data and voice communications between the automobile and the outside world. A list of key communications technologies with their frequencies, modulation schemes, maximum coverage range, data rates, and applications are summarized in Table II.

C. Broadcast Device

The broadcast device is an audio and / or video reception device. Examples of broadcast systems are listed in Table III. Broadcast systems are one way systems. The broadcast device is packaged in a separate module and not part of the telematics module on some implementations.

D. Vehicle Interface

The telematics module interfaces with other electronic modules in the vehicle via the vehicle bus. The types of vehicle bus in new vehicles are: (1) local interconnect network (LIN) for the lowest data rate functions, (2) controller area network (CAN) for medium speed, (3) media oriented systems transport (MOST) for the high speed data rates, and (4) Flex Ray for safety-critical applications. CAN and MOST are the most common used in telematics applications.

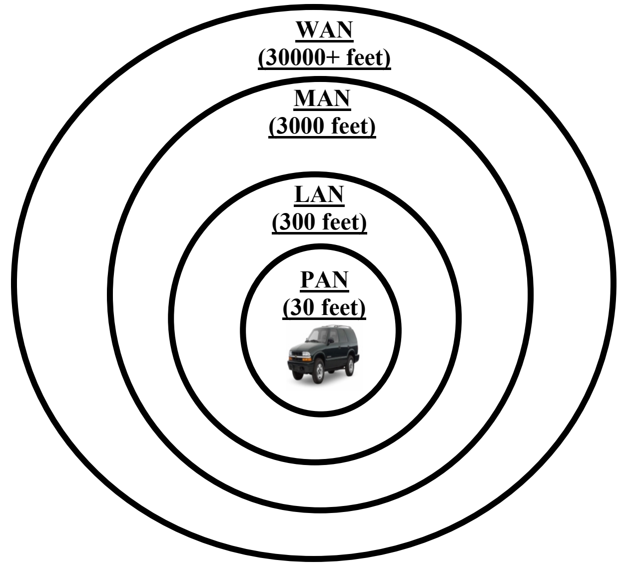

Fig. 3. Segmentation of wireless systems by overage range.

Table II: Examples of key communications technologies.

	Technology	Frequency	Modulation	Standard	Maximum Range	Data rate	Applications
PAN	Blutetooth	2.4 GHz	FHSS/GMSK	IEEE802.15.1	100 m	1 Mbps	Cable replacement, cell phone headset, peripherals, remote door unlock
	Zigbee	868, 915 and 2400 MHz	DSSS/O-QPSK	IEEE802.15.4	75 m	20, 40, 250 Kbps	Home, building, Industrial monitoring and control
	RFID	125KHz, 134 KHz, 13.56 MHz, 915 MHz	ASK	ANSI, ISO/IEC, EPCGLOBAL	1m	<100K bps	Tagging, ID, tracking
	UWB	3.1 to 10.6 GHz	DS and OFDM	None	10 m	100, 1000 Mbps	Video, data
LAN	WiFi	2.4, 5.8 GHz	CCK, OFDM	IEEE 802.11	100 ft (indoors), 300 ft (outdoors)	11, 54 Mbps	Data, email, internet access
	DSRC	5.9 GHz	OFDM/QPSK	ISO TC204 WG16 and IEEE P1609	1000 m	6 to 27 Mbps	Vehicle to vehicle, vehicle to infrastructure, infrastructure to vehicle communications
MAN	WiMax	2.5, 3.5, 5.8 GHz	BPSK, QPSK, QAM,	IEEE 802.16	10-30 KM	75 Mbps	Broadband access, back-haul
WAN	GSM, GPRS, EDGE	800, 900, 1800, 1900 MHz	GMSK, 8PSK	ETSI, ITU	10-30 KM	128, 384 Kbps	
	CDMA 2000 (1xRTT, EV-DO, EV-DV)	800, 900, 1800, 1900 MHz	DSSS, QPSK	TIA	10-30 KM	157 to 2000 Kbps	
	UMTS/3GPP/HSDPA	1.9 to 2.1 GHz	BPSK	ITU/3 GPP	10 KM	2, 10 Mbps	voice, SMS, email, internet

Table III. Examples of key broadcast systems.

System	Frequency	Modulation	Bandwidth
AM (USA)	0.53 to 1.71 MHz	Amplitude Modulation	10 KHz
Long Wave (EU)	0.153 to 0.282 MHz	Amplitude Modulation	3 KHz
Medium Wave (EU)	0.531 to 1.611 MHz	Amplitude Modulation	9 KHz
FM	87.7 to 107.9 MHz (USA) 87.5 to 108 MHz (Europe)	Frequency Modulation	200 KHz (USA) 100 KHz (Europe)
Digital Audio Broadcast-Terrestrial (DAB-T)	174 to 230 MHz	DQPSK	1.536 MHz
Digital Radio Mondiale (DRM)	0.1 to 10 MHz	OFDM / QAM	≤ 20 KHz
Digital Video Broadcast-Terrestrial (DVB-T)	470 to 861 MHz	OFDM / QAM	6 to 8 MHz
SDARS (USA)	XM 2.32 to 2.345 GHz Sirius	OFDM (Terrestrial) QPSK (Satellite)	12.5 MHz
High Definition Radio (HD)	0.53 to 1.71 MHz 87.7 to 107.9 MHz	Hybrid (analog AM/FM + OFDM) All digital (OFDM)	≤ 400 KHz

III. SDR OVERVIEW

The SDR forum defines SDR as: "Radios that provide software control of a variety of modulation techniques, wide-band or narrow-band operation, communications security functions (such as frequency hopping), and waveform requirements of current and evolving standards over a broad frequency range", [10]. The goals for SDR are: (1) ultimately to implement, mostly using software, radios that can transmit and/or receive at any carrier frequency and using any air interface protocol, (2) easy and fast integration of new technologies, and (3) reduce system cost. All of these goals fit into the telematics business model. This section provides an overview of SDR benefits, challenges, tiers and main blocks in telematics.

A. SDR Benefits

The SDR benefits for telematics industry include the following.

- Technology flexibility: a reconfigurable hardware that supports multiple carrier frequencies and protocols will provide technology flexibility for telematics service providers.
- Business flexibility: SDR allows the telematics service provider to be dynamic in choosing network partners and seeking out other markets by reprogramming a generic hardware to support the technology offered by a network provider based on customer demand and on the region where telematics services will be offered.
- Reduce time to market: SDR can result in reducing development cycle.
- Potentially reduce development cost: a reconfigurable hardware can result in reducing development cost through the use of generic hardware platform and the reuse of common software blocks.
- Reduce warranty cost: SDR will ultimately enable over the air download of product updates and SW fixes. This will result in reducing warranty costs.

All of these benefits provide opportunities for SDR in telematics industry.

B. SDR Challenges

The SDR faces the following challenges in the telematics industry:

- Cost: the cost of a software radio has to be less than or equal to the cost required to develop a conventional telematics hardware for SDR to be widely deployed in telematics.
- Horsepower requirements: implementing several protocols in software radio requires high processing power. Automotive grade processors have limited processing power that is not sufficient to implement multiple protocols. Table IV summarizes the key environmental requirements in automotive and compares them to the consumer and industrial requirements, [11].
- Wideband versus multiple antennas: antennas that support several carrier frequencies, isolation, bandwidth, gain and polarization requirements are required for SDR. Wideband antennas provide easy integration but it's challenging to meet gain, isolation and polarization requirements of different standards. Multiple antennas can meet polarization, isolation and gain requirements but they have higher cost and integration challenges.
- Simultaneity. The ability to operate several protocols and frequencies simultaneously on the software radio at the same time is one of the challenges that faces SDR in telematics.
- Download security: appropriate security protocols must be implemented for over the air downloads.

Table IV. Key environmental requirements.

Parameter	Consumer	Industry	Automotive
Operational temperature	0° C to 40 ° C	-10° C to 70 ° C	-40° C to +85 ° C
Operation time	1-3 years	5-10 years	Up to 15 years
Humidity	Low	Environment	0% up to 100%
Tolerated failure rates	<10%	<<1%	Target: 0

➢ Analog to Digital Converters (ADC) dynamic range and speed. ADC and equalizers are critical to the design of a SDR. The performance of ADCs, especially in a high mobility environment, can significantly affect the design and overall performance of SDR automobile-based integrated receivers. The automobile motion may induce Doppler shift on the timing jitter of ADC which will affect the ADC performance. The effect of ADC timing jitter and dynamic range limitation and equalization techniques on the performance of SDR must also be investigated in the development of an automobile based SDR.

C. SDR Tiers

The SDR forum defines five tiers of software radios based on the level of capability and flexibility, [10]. Tier 0 devices, known as hardware radios (HRs), implement all the radio functionality in hardware and any changes in functionality require physical intervention to implement. Multiple HRs is required to support several frequencies and protocols.

Tier 1 devices are known as software-controlled radios (SCRs). SCRs implement the control functions in software only. Multiple hardware transceivers are required to support several protocols. Software controls are used to choose which transceiver to activate. An example of this type of device is the dual-mode embedded telematics hardware supporting both advanced mobile phone system (AMPS) and code division multiple access (CDMA).

Tier 2, known as SDR, employs software to control various modulation techniques, wideband and narrowband operation, security, and the waveform requirements of current and evolving standards over a broad frequency range.

The ideal software radio (ISR) or Tier 3 includes all the features of Tier 2, but eliminates the analog amplification or heterodyne mixing prior to digital-to-analog conversion. Programmability extends over the entire system, with all analog conversions taking place at the antenna, speaker, and microphone in the case of a cellular handset.

The ultimate software radio (USR) or Tier 4 includes all features of Tier 3. In addition, USRs accepts fully programmable traffic and control information and supports a broad range of frequencies, air-interfaces & applications software. SCRs can switch from one air interface format to another in milliseconds.

D. SDR Tier and Key Blocks for Telematics

Tier 3 and Tier 4 are far from being realized due mainly to technological limitations. Therefore, the most practical Tier for telematics applications is SDR or Tier 2. A block diagram of SDR transceiver is shown in Fig. 4. As shown in Fig. 4, the key blocks are the: (1) analog domain which consists of the antenna and RF front end, (2) analog to digital converter (ADC) or digital to analog converter (DAC), and (3) the digital domain which implements all functions after ADC or before DAC in signal processing. The signal processing functions can be implemented in a GPP, DSP, field programmable gate array (FPGA), configurable computing machines (CCM) or a hybrid of GPP, DSP and / or FPGA. Table V summarizes the signal processing approaches for software radios with key vendors, and features, [12]. The key selection criteria for signal processing approach in telematics applications are:

- Automotive grade.
- Cost.
- Flexibility.
- Size.
- Level of integration.
- Development cycle.
- Performance
- Power during standby mode.

IV. CONCLUSIONS

SDR is a promising technology that has the potential to realize cost-effective, multi-band and multi-standard telematics products with reduced development cycle. SDR has many opportunities and challenges in the telematics industry.

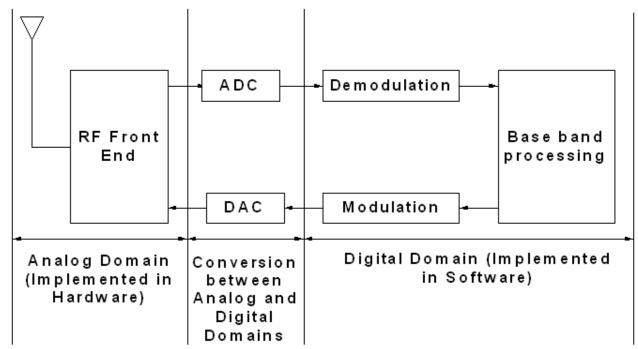

Fig. 4. A block diagram of SDR transceiver.

Table V. Signal processing approaches for SDR.

Approach	Key Vendors	Key Features
GPP	Vanu	Software available off the shelf
DSP	Sandbridge, Texas Instrument, Freescale, Analog Devices	Flexible, tailored for specific DSP applications, parallel/sequential operations, multiprocessing configurations, tools are refined, fast time to market, some architectures are automotive grade
FPGA	Xilinx, Altera, Quicklogic	Automotive grade, high speed, available IP cores, Hardware Description Language (HDL) used to describe a circuit behavior, libraries available for a variety of communication functions, in-the-field re-programmability possible, higher degree of parallelism and pipelining
Hybrid of GPP, DSP and/or FPGA	Spectrum Signal Processing, Red River,	Flexibility, hybrid approaches can be used to overcome limitations of stand-alone approaches, FPGAs handle

	Harris, Harman/Becker	operations that require high processing requirements (front end down conversion, filtering, demodulation), DSP handles audio algorithms, and GPP handles operating systems and operations that require low processing power
CCM	Quicksilver Technology	CMM increases performance and silicon utilization efficiency through logic recycling using FPGA and FPGA-like devices, improved flexibility, run-time reconfiguration, efficient utilization of silicon and power consumption

REFERENCES

[1] P.S. Hall, and E. G. Hoare, "Automobile Telematics: The Challenges for Antenna and Propagation", *IEE 11th International Conference on Antenna and Propagation*, vol. 1, no. 480, pp. 246-251, April 2001, Manchester, UK.

[2] D. N. Aloi, L Fay, M. Ronning, and M. Willer, "The Role of Bluetooth-Equipped GPS Receiver in Intelligent Transportation Systems", *Proceedings of the ION 59th annual meeting*, pp. 372-378, June 2003, Albuquerque, New Mexico.

[3] M. Alsliety, "How Does SDR Fit the Telematics Model?", *Software Defined Radio Forum Workshop on Software Portability*, June 2004, Toronto, Canada.

[4] M. Diaz, "Integrating GPS Receivers into Consumer Mobile Electronics," *IEEE MultiMedia*, vol. 06, no. 4, pp. 88-90, October-December 1999.

[5] S. Pradhan, "Mobile Commerce in the Automobile Industry", *Proceedings of the International Conference on Information Technology: Computers and Communications (ITCC03)*, pp. 276-280, April 2003.

[6] J.O. Smith, F.A. Kamangar, N. Ravi, G. Cowin, and K.U. Shah, "Anticipating the Future of Telematics", *Proceedings of the IEEE International Conference on Networking*, *Sensing and Control,* vol. 2, pp. 1276-1282, March 2004.

[7] Telematics update article: "GM's OnStar to feature automobile diagnostics service". www.telematicsupdate.com/print.asp?news=47757

[8] Y. Zhao, "Mobile Phone Location Determination and Its Impact on Intelligent Transportation Systems", *IEEE Transactions on Intelligent Transportation Systems*, Vol. 1, Iss. 1, pp. 55-64, March 2000.

[9] R.E. Ziemer, and W.H. Tranter, *Principles of Communications*, 4th Edition, John Wiley & Sons, Inc., New York, 1995.

[10] www.sdrforum.org.

[11] R. Kallenbach, and R. Bosch, "Automotive Electronics – what makes them so special?", *IEEE Vehicular Technology Society News*, Vol. 52, No. 2, Iss. 10685731, May 2005.

[12] J.H. Reed, Software Radio, A Modern Approach to Radio Engineering, Prentice Hall PTR, New Jersey, 2002.