CHALMERS

Evaluation of Radio Implementations for Emergency Call Systems, Focusing on Low Cost Solutions and Software-Defined Radio Technology

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Abstract

While the emergency call (eCall) system is becoming legislated in Europe by 2010, it may bring a potentially large market to some of its stakeholders. Both public and private sectors have some progress in eCall development, but while looking at the cost, it is still quite expensive and the vehicle owners are reluctant to pay for it. The cost of an eCall device is a very important factor. The report has conducted a pricing survey on different eCall implementations. By the pricing survey, all integrated eCall systems seem to cost at least €70. A low cost solution at €50 is possible, but it would have to go for a chipset solution in a standalone eCall system. Using software GPS can further reduce the cost as well as provide a better compatibility with new positioning technologies.

While the specifications of eCall are still not finalized, there is a risk of using obsolete radio technologies, if developed now. Even though there are voices proponing different technologies to be adopted, GSM and GPS are still the most suitable ones. The A-GPS, EOTD and the Galileo positioning system are also very much needed to be taken into consideration. As an in-vehicle device, the eCall system is also required to provide up-to-date radio technologies for 15-20 years, which is the expected life time of a vehicle. A software-defined radio solution would provide the desired flexibility. However, because of the limitations of today's configurable RF front ends, an alternative solution which is only reconfigurable in the digital architecture is proposed by this report.

Moreover, the report found out that reconfigurability does not equal high cost. A solution using OMAP and FPGA can give decent reconfigurability while still keeping the cost at an acceptable level. The cost for such a solution, around €100, is the same as the cost of existing commercial eCall systems but it could provide much more capabilities.

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1 Introduction

1.1 Background

The Pan-European automotive emergency call system, eCall, has been a widely discussed topic recently, as it is proposed to be a standard feature for new vehicles in the EU after 2010. When a vehicle crashes, or breaks down, an eCall device can be triggered to send out its position information to an emergency service center. The rescue group can then get to the accident area faster, an improvement which may save several thousands of lives each year [1].

Initiated by the European Commission and undertaken in the frame work of the eSafety forum [2], eCall was identified as a high priority project. The plan is to start eCall system development by mid-2007 and introduce eCall as standard equipment in vehicles entering the markets by the 1st of September 2010 [1].

It is shown by different studies that eCall can efficiently reduce road fatalities and injury numbers, bringing the public sector a lot of benefits which is even higher than the overall cost of eCall [1]. The players involved in eCall service include the automotive industry and the mobile telecommunications industry, insurance companies, public emergency authorities and public social security organizations. To these players eCall represents a promising market with 10 million new cars per year (by legislation) and a potential market with more than 200 million cars in Europe, making it a big opportunity not to be missed.

However, designing an integrated eCall device for a vehicle is associated with some potential problems and risks. First of all, the development has to start right away in 2007 if the device is going to be available in 2010. Any integrated vehicle electronics must be time aligned with the development process of the vehicle – which usually spans 3-5 years. As eCall standard is currently not completely approved, there is a risk of developing a device now which may not be functional later when the standard is finalized. Secondly, the desirable life time of an integrated eCall device is just as long as for the vehicle itself: up to 15-20 years. Comparing to the fast progress within wireless technology there is a risk that an eCall device which is designed today can be outdated very soon after its commercial availability. Finally, but not least important, the development cost of an eCall device is still considered too high for it to become widespread. Two solutions may be needed: low cost and multi services with acceptable price.

The communication technologies to provide the eCall service are currently recommended to be the GSM mobile phone system combined with the GPS satellite positioning system. GSM and GPS may seem like a safe choice since they are both well known wireless standards with many users worldwide and they are expected to remain in service for quite some time. However, despite its widespread use, GSM is only a bit more than 15 years old, and GPS has about 10 years of general service. The question is for how long these technologies will be the preferred choices for eCall services. Will they be around for 10 or 20 more years? Is it long enough to justify a complete eCall system based on their availability? Or will new technologies emerge, which are less expensive, more accurate and easier to combine with other services? It is hard to answer these questions today, no one knows. It would be a lot easier if it would be possible to design a device which could be upgraded later, if necessary, and use future technology right when it becomes available.

The eCall device design is not the only one with these problems. Reconfigurability is actually a key research area within the future wireless technologies [3]. To be able to put a useful eCall device on the market fast enough and also provide a device which can be updated with the latest requirements, a solution using software-defined radio (SDR) might be beneficial. A SDR system is a radio communication system which uses software, or reconfigurable hardware, as much as possible in signal processing and radio interface design. The eCall device could then be reconfigured if the eCall requirements are changed in the future. Other benefits of using SDR design are reducing the amount of hardware, shortening time-to-market and achieving larger volumes by having fewer variants, leading to a potential of lower costs in manufacturing.

1.2 Purpose

The aim of this report is to present and compare some potentials and realizable architectures for implementing eCall devices. The report specifically looks into the commonly adopted and low cost eCall solutions, and compares them with reconfigurable radio solutions (i.e. Software Defined Radio). The work consists of the following subjects:

- Survey of the available wireless technologies for eCall implementation, focusing on GSM and GPS
- Current status on realizable architectures for eCall on hardware-based design and SDR design
- Cost analysis of eCall devices
- Recommendation of different solutions for implementing eCall devices commercially

1.3 Outline

A brief overview of the report follows. The remaining sections are divided into the following 6 areas:

- Section 2 introduces eCall and gives a technology overview of GSM and GPS technologies which are likely to be applied in eCall devices, as well as a survey of other available wireless technologies.

- Section 3 talks about the architecture of a general radio terminal and detailed in GSM and GPS system. Then it gives a brief analysis of SDR technology and its commercial potential, with particular focus on the eCall application.

- Section 4 discusses the solutions of the traditional low cost solutions for eCall devices. First it gives the background of the related technologies, and then presents some possible eCall device architectures together with pricing information (the price is based on 100,000 units) and major providers. At the end of this section, we conclude which solution might the most suitable.

- Section 5 discusses the SDR solutions for eCall devices. The skeleton is the same as the one in section 4.

- Section 6 sums up the cost analysis of eCall and talks about the eCall business cases from different studies. Then it describes some related private services available in the market.

- Section 7 concludes the report.

2 Technology overview

2.1 Emergency Call - eCall

In order to improve road safety in European countries, the European Commission, the industry, and other stakeholders jointly established the eSafety Forum, to promote intelligent integrated safety systems by using new information and communication technologies. eCall Driving Group (eCall DG) was established at the end of 2002 to identify the key players and outline the functionality interfaces between them. The goal is to make eCall a standard option for new vehicles by September 2010.

2.1.1 Function

eCall stands for Pan-European automatic emergency call system. It can be either generated manually by pressing a button in the car or automatically via in-vehicle sensors like air-bag interface or seatbelts. When eCall is activated, a voice call based on enhanced 112 (E112) will be established and a minimum set of data (MSD) will be sent out. The MSD is set to be 140 bytes coding in 8-bit ASCII code. The data include type of activation, vehicle identification number (VIN), time stamp, location, service provider and 106 bytes of optional data [1]. The short message service (SMS) of GSM which contains exactly 140 bytes of data is subsequentially the suggested data carrier [4].

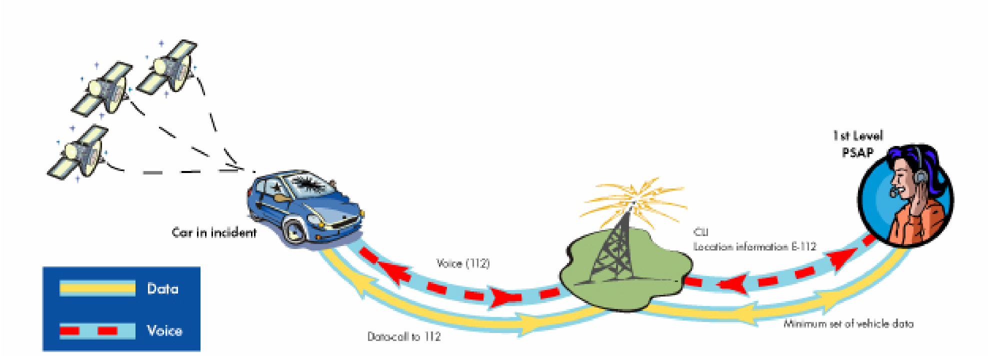

Figure 1: eCall system overview [4]

The voice-data link of eCall is required to be GSM standard. The positioning system is not yet specified but currently the only solution in Europe is GPS. As shown in Figure 1, when a car accident happens, the device initiates eCall to the Public Safety Answering Point (PSAP). The Wireless connection consisting of voice and data is carried through the mobile network (GSM) recognized by a Mobile Network Operator (MNO). The voice communication can provide the PSAP operator more details about the accident, however, regardless of if a voice communication is possible or not, an MSD consisting of information about the accident will still be sent to PSAP automatically. The PSAP should acknowledge the eCall generator when an MSD has been received. After acquiring the accident information from the eCall generator, the PSAP can then deploy ambulance and hospital preparation more efficiently.

2.1.2 Requirements

Below some specific eCall requirements are listed [1]:

- The emergency call should be given the highest priority through the mobile network.
- The minimum target for overall performance (Rate of all activated and sent eCalls successfully reach the PSAP):
  - By 2010 – 85%
  - By 2015 – 89%
  - By 2020 – 92%
- Criteria of End-to-End Timing:
  - Crash signal distribution time: < 100ms
  - Call initiation time: < 20s
  - Voice call establishment time: < 10s
  - - data transmission and visualization time: < 10s
- Criteria of eCall generator (Rate of all accidents the eCall trigger thresholds successfully be delivered to the mobile network by the eCall generator):
  - By 2010 – 90%
  - By 2015 – 95%
- Criteria of location precision:
  - ≤ 50 meters (in 50% of all cases)
  - ≤ 150 meters (in 95% of all cases)

2.1.3 eCall implementations

Two general implementation options of eCall, an embedded system a nomadic system, are now being considered by eCall DG. Using merely mobile phone for traffic emergency call has also been discussed. This report will focus on the radio implementations of the embedded system solutions. However, the implementation of the car interface or SIM card and the nomadic systems solution are briefly introduced below.

Embedded system

An embedded eCall system consists of GSM and GPS accessibilities as basic and maybe other optional hardware. The system will be embedded into the vehicle as an electronic control unit (ECU). The most common interface between a vehicle and an ECU is the CAN bus. Some other needed interfaces are: automatic trigger, SIM card control, voice speaker/microphone and manual control pad. Since eCall DG has not put forth a firm requirement for the PSAPs to be able to call back the vehicles, weather to use SIM cards or not is still debatable. One-time-use or eCall-only SIM cards are also being discussed.

Nomadic system

A nomadic device is a wireless device such as a PDA, mp3 player, or mobile phone, which the driver brings into the vehicle. Since almost everyone has at least one handset, a nomadic device to handle the voice/data link for eCall implementation has also been proposed. The navigation module (GPS) can be either embedded in the vehicle (in-vehicle navigation systems) or in the nomadic device (GPS phones or nomadic navigation systems). Because of the automatic trigger signal, car information data and handsfree function, an interface between the vehicle and the nomadic device is required. If wired connection is used, a universal socket for different devices and different brands will be needed, thus the wireless solution - Bluetooth would be a better interface.

Mobile phone for emergency call

GSM Europe (GSME) argues that the safety benefit of the eCall service is over-evaluated since the benefit brought from reducing the time between "the occurrence of an accident and the alerting of the emergency authorities" has been mostly achieved by mobile phone usage, which has a 93% penetration of the population in the European Union [5].

Since the year 2001, Europe's governments has adopted the new legislation that requires all mobile phones to provide location information for every emergency call on enhanced 112 (E112) [6]. By now E112 is operational in several countries in Europe [7]. Using mobile phones to provide crash notification instead of eCall devices has been discussed widely. Unfortunately, the location precision provided by E112 is not enough for the eCall application, which requires at least an accuracy of 150 meters in most cases. While the E112 adopted in Europe only uses the cell ID of base stations as location information, in rural area the distance between base stations can be up to several kilometers. This is definitely not good enough for crash notification applications. Improved mobile radiolocation technologies, discussed later in this report, might provide precision up to 100 meters. However, this requires the installation of software and hardware through the network and mobile phones, and cannot be updated to 3G. Therefore, they are not feasible solutions for Europe in the near future [8]. Hence, a satellite navigation system is still needed. Even though handsets with GPS features are coming, still, a handset will not make an emergency call automatically when an accident happens.

2.1.4 eCall progress

At the moment (April 2007) there are only 7 countries[1] within EU25 that have signed the Memorandum of Understanding [2] (MoU). The major countries like France, Germany and the UK still have not signed the MoU, causing the eCall introduction in

[1] Cyprus, Finland, Greece, Italy, Lithuania, Slovenia and Sweden

[2] *"The Memorandum of Understanding is an expression of the individual and collective commitment of the signatories to work in partnership in order to realise the shared objective of eCall realisation."* [4]

Europe being estimated to be delayed by two years. The biggest obstacle of realizing eCall systems is to integrate and update the PSAPs within and between each country. The existing eCall compatible devices generally provide more services than eCall and target at high-end vehicles. The major concern of the automotive manufacturers to equip eCall devices into their cars is the cost.

The eCall specifications have still not been fully agreed upon. GSME argued that using SMS to transmit emergency information is not practical because of the latency risks. The VIN in MSD is not surely required because not every PSAP can access the VIN from the cars produced in other countries [9]. The independent advisory body, Article 29 Working Party, has addressed the implications of privacy and data protection relating to the wide introduction of eCall. A suggestion is to introduce a proper data protection scheme in the eCall system if it becomes mandatory, otherwise a voluntary approach is recommended [10].

Right now, Finland and Sweden are the only two countries who both have signed the MoU and are candidates of pilot [7].

As the first country to sign the eCall MoU, Finland sees eCall as a priority action and strongly supports it. The Finnish ministry of Transport and Communications (MinTC) is aiming to implement eSafety Forum's recommendations and it has created an eCall test bench to verify the communicational operations of eCall terminals. The tests were focused on the integrity and availability of the communications. Once the eCall specifications are finalized, Finland will have a large scale trial among the candidate countries [4] [11].

Sweden has the lowest road fatality rates in Europe and a domestic automotive industry, Volvo, labeled safety as its hallmark. According to the "Zero Vision" program, the Swedish Road Administration has adopted zero fatalities or serious injuries in road traffic as its long-term goal [12]. Even being estimated to have lowest benefits from eCall with 2-4% reduction of road fatalities [13], Sweden is still dedicated to promote eCall. The government is aware of its responsibility for implementing eCall in Sweden and has started a series of plan on eCall. SOS Alarm Sverige AB, the national owned PSAP operator, is instructed to develop and run a service of receiving eCall in Sweden, as well as collaborating with other relevant stakeholders [13].

2.2 Global System for Mobile Communications (GSM)

GSM is the most popular standard for mobile phones in the world. It has almost 100% mobile coverage throughout Europe. GSM was originally set up by European Telecommunications Standards Institute (ETSI). The commercial service was launched in mid 1991 and today GSM has more than 2 billion subscribers [14]. As a consequence of its popularity, GSM is also a fairly inexpensive service these days and GSM handset prices have dropped a lot due to heavy competitions. However, GSM is not the most recent mobile phone system anymore. 3G/Universal Mobile Telecommunications System (UMTS) services are rapidly growing in Europe and within a few years it may have sufficient coverage for eCall deployment, but not at the moment.

2.2.1 Services and features

The most important service of GSM is the mobile voice service. When it was introduced, the main feature of GSM (2G network), compared to its predecessors, was that all the communicating signals in GSM are digital. The advantages of using digital signals are lower radio power requirement, digital error checking and the capability of sampling in various dynamic ranges. Also because of its digital feature GSM can provide some digital data service –Short Message Service (SMS). SMS is planned to be applied in eCall for sending the positioning information to the emergency center.

In addition to SMS, two enhanced packet data services providing Internet access have been introduced in the last ten years:

- GPRS (General Packet Radio Service) – 2.5G ~ 64 kbps
- EDGE (Enhanced Data Rates for GSM Evolution) – 2.75G ~ 384 kbps

GPRS or EDGE would be capable of sending the eCall positioning information to the emergency center. Also, any eCall device aiming to simultaneously provide any telematics services would need packet-switched connection, hence should have at least GPRS. But especially EDGE has not yet sufficiently wide coverage in Europe to be considered for eCall. Moreover, the data services make the GSM terminal design more expensive. SMS is within the GSM standard. It can be carried in circuit-switched connection and does not require any complicated design on the GSM terminal.

2.2.2 Network structure

An illustration of the GSM network structure is shown in Figure 2. The GSM network structure consists of three parts: mobile stations, base stations and network switching systems which connect to the public networks [15].

- **Mobile Station (MS):** a mobile station consists of the physical equipments (such as radio transceiver, digital signal processor and display) and a Subscriber Identity Module (SIM) card which enables personal mobility.
- **Base Station Subsystem (BSS):** BSS is composed of two parts, the Base Transceiver Station (BTS) and the Base Station Controller (BSC). The BTS communicates with MSs and the BSC manages the radio resources for one or more BTSs.
- **Network Switching SubSystem (NSS):** the central component of this subsystem is the Mobile service Switching Center (MSC) which deals with the switching works and provides connection to the public fixed network like PSTN or ISDN. The Home Location Register (HLR) and Visitor Location Register (VLR) contain

the subscriber and location information, together with the Authentication Center (AUC), the MSC can provide call routing and roaming capability of GSM.

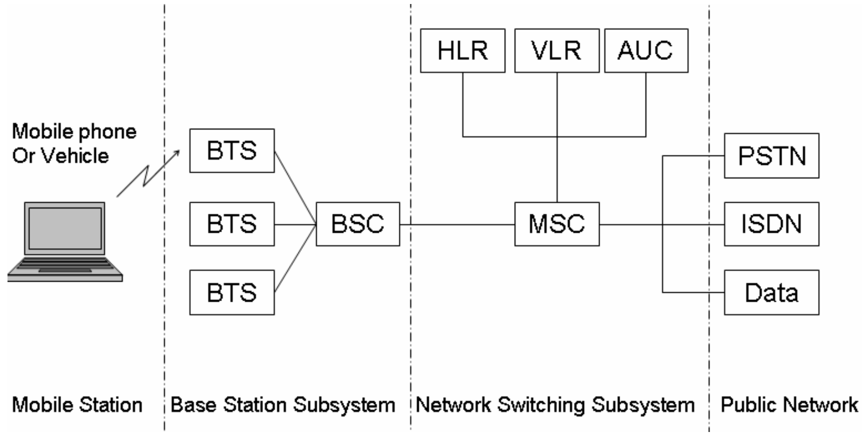

Figure 2: GSM network structure [15]

2.2.3 Radio interface

- **Modulation:** GMSK (Gaussian Minimum Shift Keying)
- **Radio Frequency:**

System (central frequency)	Uplink (MHz)	Downlink (MHz)	Channel Number
GSM 850	824 - 849	869 – 894	128 - 251
GSM 900	890 - 915	935 – 960	1 – 124
DCS 1800	1710 - 1785	1805 – 1880	512 – 885
PCS 1900	1850 - 1910	1930 – 1990	512 – 810

GSM-900 and GSM-1800 are used in most parts of the world: Europe, Asia, Austria, Africa and some countries in South America. GSM-850 and GSM-1900 are used in the North and South America [16].

- **Channel Bandwidth:** 200 kHz

2.3 Global Positioning System (GPS)

At this time, April 2007, the United States GPS is the only fully operational global navigation satellite system (GNSS). GPS is owned and operated by the US Department of Defense. It was originally intended for military use, but has been available for general use around the world since 1996. To have a global coverage, the satellite constellation has to contain at least 24 satellites. These satellites are equally distributed in 6 orbit planes, with the altitude of 20,200 kilometers above the earth and the inclination of 55 degrees to the equator. By January 2007, there are 29 operating satellites in the constellation providing a better positioning service by redundant measurements. A simple illustration is shown in Figure 3.

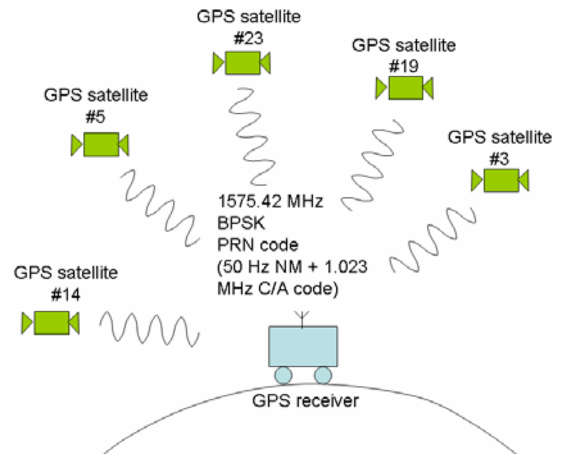

Figure 3: Global positioning system

2.3.1 Function

Each satellite contains a simple computer and an atomic clock, broadcasting its own position and current time label. A GPS receiver calculates the time difference between transmission and reception by subtracting the arrival time label (recorded from its internal clock when satellite signal arrives) from the transmit time label (contained in the satellite signal when it is transmitted). Distance can be acquired by multiplying the signal travel time and the speed of light (300,000 km per second). The GPS receiver on the ground can see 8 satellites in the sky on an average [17]. At least 4 satellites signals have to be received simultaneously in order to calculate the position precisely.

Figure 4: GPS positioning

As shown in Figure 4, theoretically the receiver's location can be calculated by knowing 3 satellites' positions and ranges from the receiver, but in the reason of the inaccuracy of clocks, the range measurements could be very much incorrect. The atomic clock of each satellite updates regularly and can said to be accurate but the local clock at receiver side can shift for many reasons like temperature changes. Consider that a local clock is off by 0.1 microseconds, the range would be 30 meters too long. The fourth measurement is essential to correct the receiver's internal clock. Adding more satellite signals into consideration can increase the accuracy.

Adding up all the sources of error: atmosphere medium, satellite clock offset and electronics signal offset, a normal reception of a civilian GPS receiver can have positioning accuracy in a few meters [18]. GPS signals become very weak when they reach the surface of the earth. Thus GPS receiver requires free line-of-sight to the satellites and this is the reason of bad reception indoors or in urban areas. Therefore using an external antenna is usually needed for an embedded positioning device.

2.3.2 Radio Interface

- **Modulation:** BPSK (Bipolar-Phase Shift Keying) as shown in Figure 5.
- **Radio Frequency:** L1: 1575.42 MHz. The common carrier frequency for civilian usage.
  L2: 1227.60 MHz. Encrypted signal mainly used by military.
- **Channel Bandwidth:** 2.046 MHz. Binary phase shift keying at 1.023MHz has a power spectra with most of its power contained within a frequency range twice the bit rate.
- **Signal Strength:** -160 ~ -155 dBm, on earth.

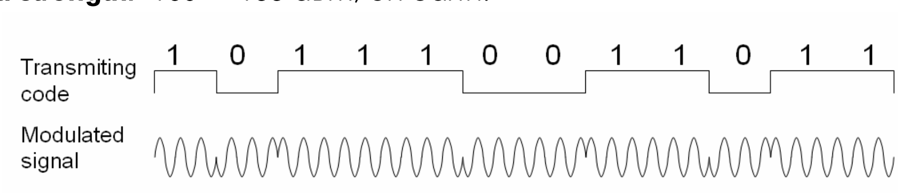

Figure 5: BPSK modulation

2.3.3 Navigation Signal

The GPS navigation signals are transmitted in pseudo random noise (PRN) code sequence which is the module-2 addition of the 50Hz navigation message and the Coarse/Acquisition (C/A) code, shown in Figure 6. C/A code is a 1,023 bits pseudo random code broadcasting at 1.023 MHz, repeating every millisecond.

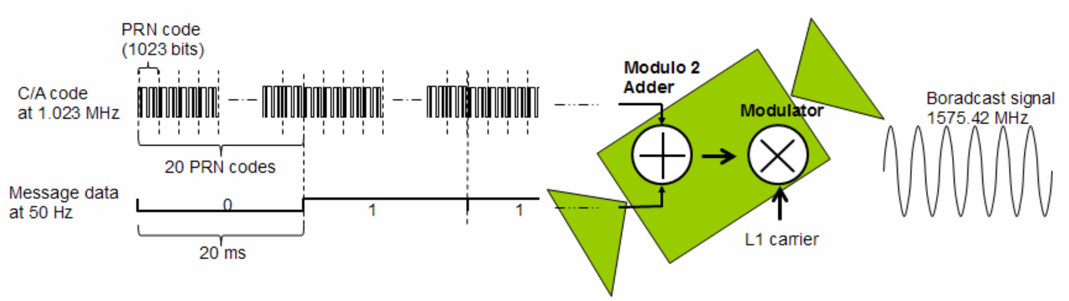

Figure 6: GPS navigation signal

GPS uses CDMA (Code Division Multiple Access) to reduce the interference between the signals from different satellites. Every satellite transmits its unique C/A code in the same L-frequency band. Each C/A code is generated by different phase selector but using the same basic code generator.

2.3.4 Navigation Message

The basic message structure is a 1500 bit long frame containing five subframes. The data contained in each subframe is shown in Figure 7. Each subframe is 300 bits long and consists of ten words, each 30 bits long. The navigation message is sent at 50 bps rate. Subframe 4 and 5 are commutated 25 times each, so a complete data message will require the transmission of 25 full frames, which takes 12.5 minute. The position and time information of the satellite itself will be broadcasted in every frame (in subframe 1~3), which repeats every 30 seconds [19]. When a GPS receiver is started after being off for a few days, it needs to find the satellites' positions again. The GPS receiver needs to receive at least 4 complete navigation messages. This is the reason why the GPS receivers usually take at least 40-45 seconds when they are in the "cold start" period.

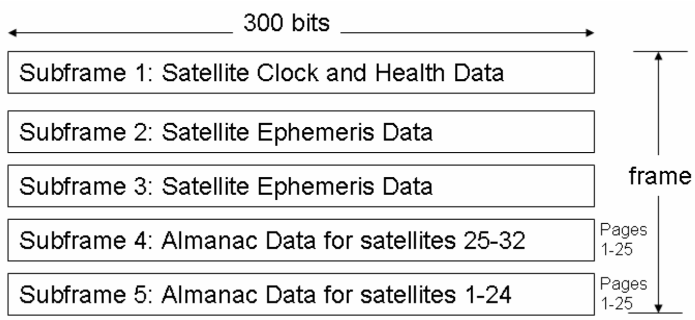

Figure 7: GPS message structure

2.4 Future technology improvements that could change the eCall requirements and design

2.4.1 GNSS compatibility

Galileo positioning system

The European version of satellite navigation system is argued to be a necessary adoption of eCall system because it will provide an independent and reliable positioning service in case of wars or political disagreement. With the first test satellite launched in December 2005 and the second launch postponed from autumn 2006 to early 2007, Galileo positioning system is planned to operate by 2010, two years delayed than first anticipated. This may as well cause the delay of the introduction of eCall.

The Galileo OS (Open Service, which is free) signals will be broadcasted at 1164–1214 MHz and 1563–1591 MHz (same as GPS L1) with higher accuracy than that provided by GPS. All Galileo satellites will operate in the same nominal frequency, using CDMA compatible with GPS approach. It's expected that the future positioning receivers will process both GPS C/A and Galileo OS signals, to enhance coverage and performances.

Two major differences between Galileo and GPS are:

- Satellite constellation: Galileo will contain 30 satellites (27 operational and 3 active spares) equally distributed in 3 orbit planes, with the altitude of 23,616 kilometers above the earth and the inclination of 56 degrees to the equator. The higher angle of inclination gives better coverage in Northern countries, such as Scandinavia countries [20].
- Navigation signals: Galileo uses longer PRN codes and Binary Offset Carrier (BOC) instead of BPSK in GPS. These improvements will reduce cross-correlation and multipath problems [21] [22].

GLONASS

Held by the former Soviet Union, GLONASS is now jointly deployed by Russia and India. When this report is being progressing (March 2007), there were 19 satellites in orbit, of which 9 were in operation, 7 "temporarily switched off" and 3 in "commissioning phase" [23]. GLONASS is scheduled to be fully deployed with 24 satellites by 2011. Using FDMA, the signal structure of GLONASS is much different to the signal structure of GPS than Galileo. But somehow, the interoperation of GLONASS, Galileo and GPS is technically easy [24]. Many commercial GPS receiver can receive GLONASS signals as a backup.

Beidou Navigation System

Independently developed by the People's Republic of China, Beidou Navigation system is announced to provide open service covering China region from 70°E to 140°E, and 5°N to 55°N in 2008. China also indicated that the Beidou navigation system will be expanded to a global system. Compare to GPS, Beidou navigation system which uses a different system constellation is argued to have many problems like requiring transmitter in the positioning device, limited amount of users and high dependence on central control system…etc [25].

GPS modernization

A GPS modernization project involving new ground stations and new satellites aims to provide improved navigation services, three new navigation signals: L1C, L2C and L5, by 2013. L1C uses L1 frequency band but increases signal power by 1.5dB. L2C is in L2 frequency band, transmitted in higher bit rate (10.23 MHz) and stronger signal. This allows the GPS receivers to acquire 10 times accuracy than using L1C and also reduce power consumption. The dual-frequency receiver can have positioning errors on the order of one centimeter but is typically expensive (US$ 10,000). L5 (1176.45

MHz) is set to be first launched in 2008, primary designed for life saving applications [26].

2.4.2 Mobile communication future

Since GSM became a commercial service in 1991 it has evolved through GPRS (2001), EDGE (2003) UMTS (3GSM, 2003). The latest adopted mobile communication technology in Europe, UTMS, covers wide region in West Europe, and is still growing. The next generation 4G is coming in the near future. Currently GSM seems to be a safe choice for eCall communication link but the technology may phase out in the future.

GPRS requires the same hardware as GSM does and is compatible with GSM hardware. EDGE uses the same frequency as GSM but different modulation scheme and coding thus requires new hardware in baseband, when using a dedicated hardware baseband. UTMS is using a different frequency band (1885-2025 MHz for uplink and 2110-2200 MHz for downlink) and air interface thus requires a completely new terminal hardware. If wanted the communication system to be compatible with modern technologies, some hardware pre-installation would be needed.

2.4.3 Location-based services

Location-based services (LBS) offer mobile phone users the information of where they are and the surrounding services. The position is obtained either by an embedded GPS receiver in mobile phone (handset-based solutions) or by radiolocation via cellular base stations (network-based solutions). The services are most adopted in North America. In the U.S. the Federal Communications Commission (FCC) mandate requires 95% of handsets resolve within 300 meters for network-based tracking and 150 meters for handset-based tracking (i.e. GPS) [27]. In Europe, the LBS are just for emergency service E112 and only operational in some countries. There is no strong regulation like the U.S. but it is predicted that LBS would have a strong growth in Europe [28].

The network-based solutions mean that the users obtain their positions with the help of the servers of cellular base stations. Normally network-based solutions only require modification in base stations but not in handsets. The drawback is that when the users are outside the network, the position services are no longer available. Network-based solutions include Cell-ID and improved triangulation methodologies. **Cell-ID** has already been commonly adapted by mobile network operators and is operational in some countries in Europe, but the accuracy (several kilometers in rural area) is clearly not able to meet the requirement of emergency service.

Triangulation methods locate the position by measuring the time differences from three different stations. **Enhanced observed time difference** (EOTD) is the only solution in Europe. It gives accuracy around 100 meters but requires software installations in mobile phones since the position is calculated in the mobile phones. The Matrix system of Cambridge Positioning Systems Ltd. (CPS) is an example. Two other methods used in USA are **advanced forward link trilateration** (AFLT) in CDMA networks and **time difference of arrival** (TDOA) in GSM networks. AFLT also gives around 100 meters in accuracy and requires software changes in handsets. TODA does not require modification in handsets but its accuracy is only around 300 meters [29][30].

The handset-based solutions mean the locations are obtained by the handsets using GNSS. Embedded GPS is the only solution now. Assisted GPS (A-GPS) uses assistance servers such as mobile location servers (e.g., cellular base stations) to determine a position more quickly and efficiently. The assistance server can provide GPS receiver: satellites ephemeris and clock information as well as initial position estimation. Moreover, the assistance server may also compute position solutions so the GPS receiver should only need to collect range measurements. The data is sent to mobile phones using Hypertext Transfer Protocol (HTTP) or SMS. A-GPS is generally more accurate when compared to network-based positioning, but still, indoor signals are too weak for GPS tracking. The servers can provide A-GPS receivers information for a faster tracking but the signals still have to be tracked by A-GPS receivers themselves. A large number of correlators for massive parallel correlation are required for A-GPS receivers to work indoors [31].

Since both A-GPS and network-based solutions have their weaknesses in urban area and rural area respectively, a hybrid solution, enhanced GPS (E-GPS), combining GPS and EOTD is introduced by the cooperation of CPS and other GPS venders (Trimble and SiGe semiconductor). Most of the time the GPS can give more accurate position estimations, but when the GPS signals are too weak or taking too long to acquire, EOTD is then used. An E-GPS receiver can choose between the above two technologies therefore provides a higher coverage and faster service. E-GPS is similar to A-GPS in the way of deriving network servers' reference timing information for faster position estimation, but the network servers in Europe do not communicate with GPS satellites thus will not provide satellite ephemeris data. While indoor, the E-GPS receiver may use EOTD to calculate where it is [32].

3 Radio systems and reconfigurability

3.1 General architecture of wireless terminals

As shown in Figure 8, a general wireless terminal consists of an antenna, a RF front-end, a baseband unit and a general purpose microprocessor. Usually the antenna is used for both receiving and transmitting signals. A RF front-end is mostly designed in an application-specific integrated circuit (ASIC) and with analog components. It is to convert receiving RF signals to lower frequencies as well as convert baseband signals to transmitting RF signals. Between the RF front-end and the baseband unit, receiving signals are sampled at the analog to digital converter (ADC); transmitting signals are converted at digital to analog converter (DAC). The interface between the RF front-end and the baseband unit can be digital or analog, that means the ADC/DAC can be located at the baseband unit or at the RF front-end. The baseband usually consists of modulation/demodulation, encryption/de-encryption and channel coding/decoding. It can be said that the baseband implements the physical layer of the OSI reference model. In wireless handsets, most of the baseband units are designed in ASICs because of speed and power factors. Some of the functions can be done by a digital signal processor (DSP) but normally it is a closed chip, never updated or changed during its lifetime. The higher protocol layers in wireless communications run on a general purpose processor, provided that power requirements can be met.

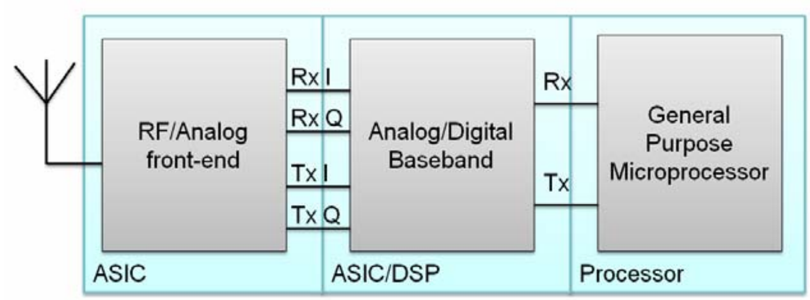

Figure 8: General architecture of wireless terminals

3.1.1 GSM mobile terminal architecture

A GSM mobile terminal and its functions are shown in Figure 9.

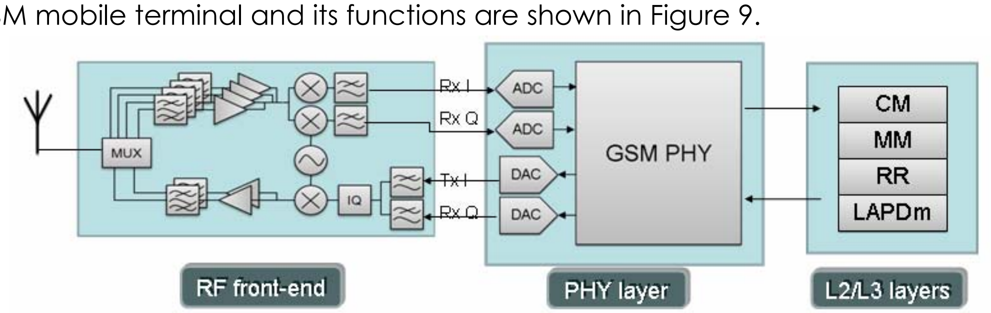

Figure 9: GSM mobile terminal architecture

- **Antenna:** GSM signals are not very sensitive to receivers, so normally an antenna patched on PCB board would give a decent reception.
- **RF front-end/Analog Front-end:** The RF front-end, as shown in Figure 10, is to down-convert the RF signals (e.g., 850MHz) to a lower frequency range (from 0 to 10 MHz). Because transmitting (Tx) and receiving (Rx) parts uses the same antenna, a Tx/Rx switch is needed. A multi-band receiver usually has a multiplexer to select the receiving frequency, followed by band pass filters and low noise amplifiers (LNA). There are different ways of doing down-conversion. In a two-stage receiver, the amplified signals will be down-converted to an intermediate frequency (IF) (e.g., 70-300 MHz). The IF signals are then usually separated into two and mixed with a local oscillator (LO) with one of the signals mixed at 90 degrees shift (sine waveform). The two signals are demodulated into in-phase and quadrature-phase (IQ) signals. In contrast to two-stage or multi-stage conversion, direct-conversion receivers down-convert the RF signals directly to baseband signals at the IQ mixer. This type of radio receiver had some technological problems limiting its use in the past, but is now very commonly used in GSM front-ends. Some of the technological problems are relieved because the complete phased-lock loop can now be incorporated in a low-cost IC package, so that the LOs can remain in high accurate frequency when taking receiving signals as reference. In the transmit part, the RF front-end modulates the Tx IQ signals to the transmitting RF signals. The signals are up-converted directly from baseband to RF signals and conducted onto the antenna.

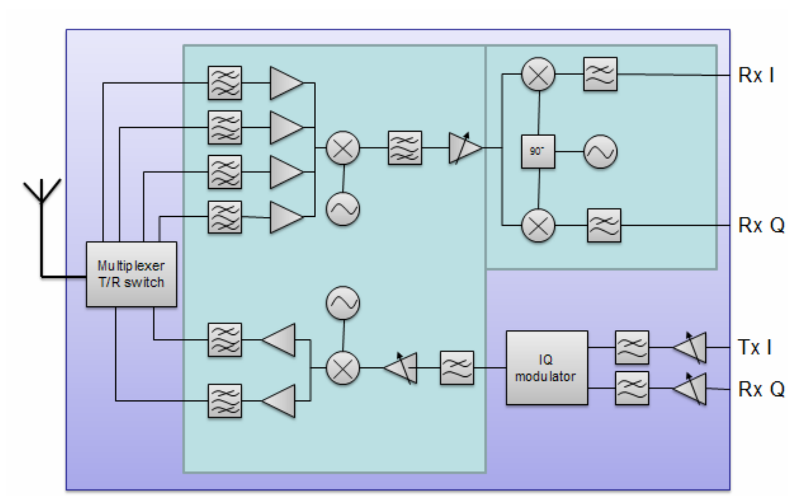

Figure 10: GSM quad-band RF front-end

- **Baseband:** followed by low-pass filters and amplifiers, IQ signals are sampled at ADC and then demodulated. After de-ciphering, de-interleaving and channel decoding, it becomes original raw data. A high performance reduced instruction set computer (RISC) processor or a CPU with DSP-like co-processor is integrated into a ASIC to handle the physical layer (PHY) controlling functions and signal processing. Data is then passed on to higher layers, L2/L3, and either become control data or decoded by speech codec to voice. The transmitting part follows the same route as the receiving part but in a reversed process. Some of the manufacturers (like Texas Instrument) integrate the ADC/DAC with both GSM codec and speech codec as well as other analog processes into one analog baseband chip, so that one ADC/DAC can be shared by all analog/digital uses.

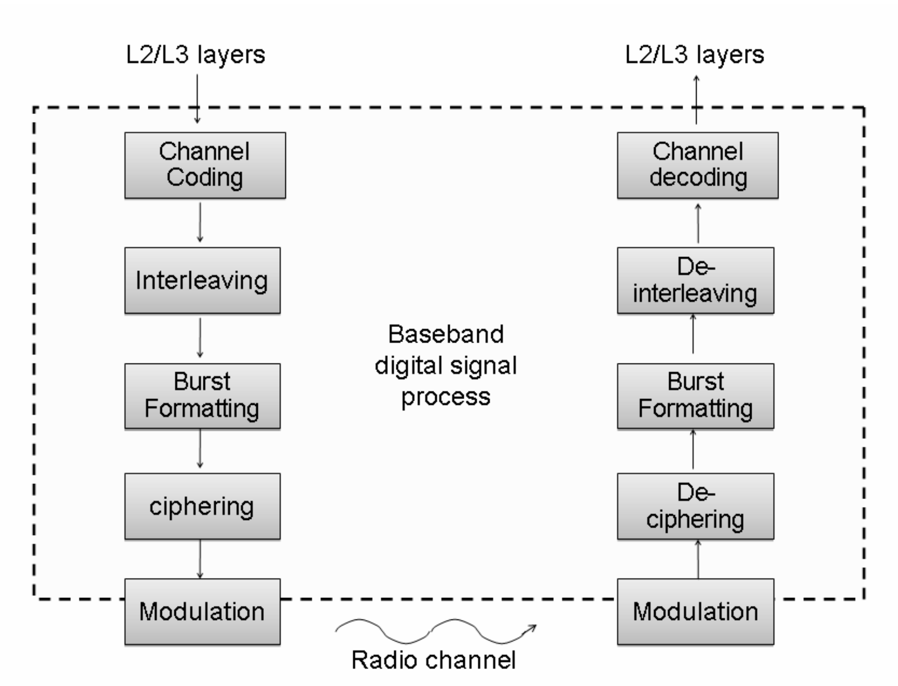

Figure 11: GSM baseband signal processing [15]

- **Layer 2 / Layer 3:** the upper layers fulfill the functions between Physical layer and application layer. Layer 2 is similar to Data link layer in the OSI reference model and responsible for establishing a data link. The data frame contains address, control, length and data. It provides pseudo-link for layer 3 between mobile terminals and base transmit stations. Layer 3 consists of Radio Resource Management (RR), Mobility Manager (MM), Connection Manager (CM) and Mobile Network (MN). The higher protocol stacks are implemented in a general purpose microprocessor.

3.1.2 GPS receiver architecture

A GPS navigation device only receives signals from satellites and calculates its position from them. It doesn't need to transmit signals. A GPS mobile terminal and its functions are shown in Figure 12.

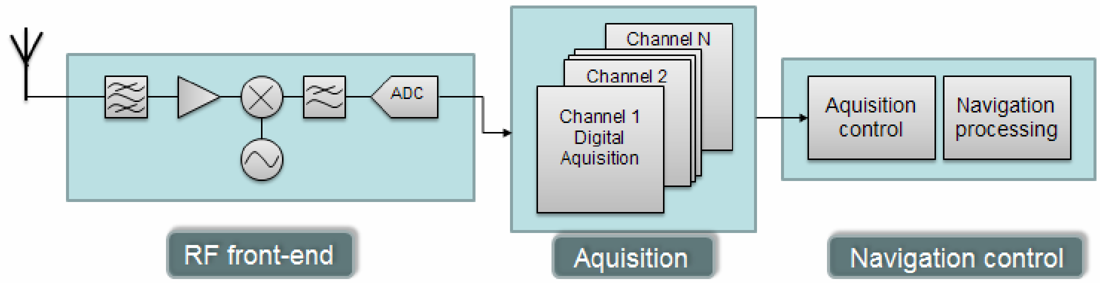

Figure 12: GPS receiver architecture

- **Antenna:** GPS signals are very weak and usually require clear line-of-sight, thus an external antenna is usually needed for an embedded system.
- **RF front-end:** RF signals received from the antenna pass through a band-pass filter and a LNA, then down-converted to the final IF closed to baseband (e.g., 4 MHz). Single stage down-conversion is prevalent, but multistage down-converter allowing for adequate image suppression at higher IF (e.g., 30-100 MHz) is better at reducing jamming problems. The final IF signals are then converted to baseband IQ signals. This final conversion from IF to baseband IQ signals can be accomplished either after or before ADC. For low-end commercial receivers, 1 bit sampling in a narrow band (2 MHz) ADC is fairly enough and often used. This can be easily implemented by a D-type flip-flop. Other ADC ranging from 1.5 bit (3 levels) to 3 bit sampling and bandwidth from 2 to 20 MHz can be found in high-end receivers. Even though the GPS C/A code bandwidth is only 2 MHz, using higher sampling rate can still achieve better signal resolution and therefore improve the performance [33].

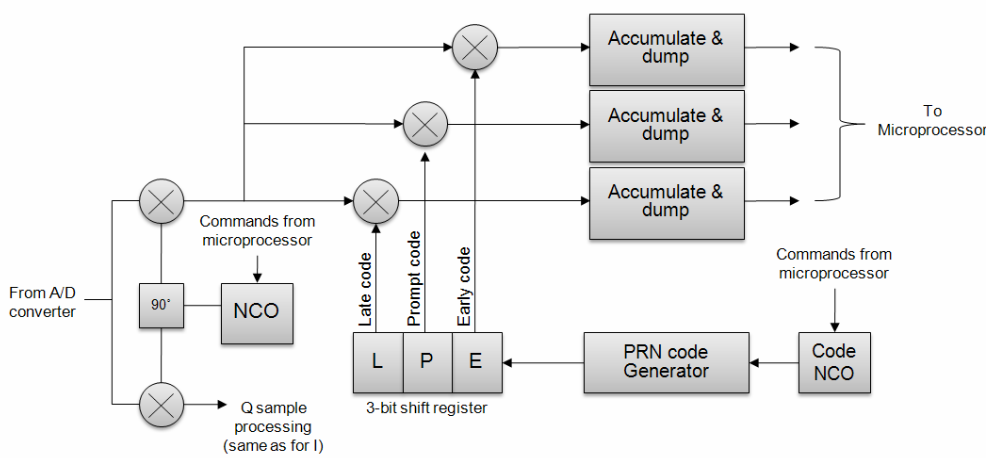

Figure 13: GPS acquisition baseband

- **Digital baseband:** as shown in Figure 13, the sampled signals from RF front-end are demodulated into IQ signals and mixed with numerically controlled oscillator (NCO). The received IQ signals are individually mixed with a host generated PRN code, and then accumulated to form the correlation values.

In order to remove the Doppler frequency shift, early, prompt, and late versions of the host PRN code are used in correlation, as well as using delay-lock loop (DLL) feedback to NCO. The accumulation period is 1ms when bit non-synchronized, but 20ms when bit synchronized [33].

- **Microprocessor:** DSPs are usually used to form navigation calculation and acquisition feedback.

3.2 Reconfigurability and Software-defined radio

3.2.1 Reconfigurability

The fast evolution of wireless technologies and the different wireless networks in various geographic regions caused a multiplicity of radio access technology (RAT) standards existing today. This has created a need for multi-standard terminals (MST) capable of supporting different wireless technologies. A MST can be achieved by combining different hardware of existing radio technologies, but reconfigurability which allows radio transceivers to be able to upgrade or adjust without changing hardware is the optimal goal. Four levels of reconfigurability are: during manufacturing, prior to purchase, following purchase, and in operation [34]. Some levels of reconfigurability are commonly achievable by new manufacturing technologies, but the complete reconfigurability is still not commercially realized yet.

The benefits of reconfigurable MST are:

- **Huge economy of scale.** Since the terminal controls the air interface operation in software, it is possible to manufacture a single reconfigurable terminal and configure it at the final stage of manufacture to any particular market. This tremendously reduces the costs in reason of manufacturing in large amount and low variants.
- **Global Roaming**. The present different mobile standards and the gradual migration from 2G to 3G systems caused the varied network technologies exist in different region (even in a single nation, exist different mobile standards). A MST can support different network technologies and use the most suitable one in different situations.
- **Reconfiguration/upgrading ability.** When encountered with a new network either in visiting another country (e.g., visiting from Sweden to Japan) or when new technology invented (e.g., the launch of UMTS on GSM network), the mobile terminal can download (on-air or manually) new software to cope with new networks and enjoy a seamless connection.

3.2.2 Software-defined radio (SDR)

A method to efficiently design MSTs and reconfigurable radio is software-defined radio (SDR).

A SDR is a form of radio using versatile, general-purpose hardware which is controlled by software. A SDR platform is targeting to replace dedicated hardware by reconfigurable hardware or software as close as much to the antenna. Ideally, a software-defined radio is to have an ADC right after antenna sampling the RF signals to digital signals. All digital signals will then be manipulated in a high performance DSP or microprocessor. This ultimate terminal may never be realized because of the limitation of RF components and ADC/DACs.

While SDR is being promoted enthusiastically by its proponents, the technology still today is considered not mature enough to achieve complete reconfigurable wireless platforms. The required high performance ADC and wideband RF front-end cause high power consumption, which is the main reason why SDR hasn't been persuaded by handset manufacturers today since the operating time of the mobile battery is a crucial factor in mobile performance. In vehicles, the power is not a critical issue thus a SDR solution is acceptable. On the other hand, while telematics services are getting more and more awareness between automotive manufacturers and users, the major issues of telematics systems, keeping the technologies up-to-date in old cars and long development time, seems can be solved by SDR technology. For the above two reasons, SDR would be the best solution for telematics devices.

3.2.3 SDR system approach

A SDR terminal is usually required to operate in wideband or multi-band. The RF components including antenna, filters and amplifiers need to operate in a frequency range of a few gigahertz (e.g., 850MHz to 2.4GHz). If sampled at the RF frequency, the ADC has to work in at least 5GHz (if using Nyquest sampling at ISM frequency band - 2.4GHz) and high dynamic resolutions in about 20 bits [34]. These wideband RF components and high performance ADCs require very high power consumption and costs. Thus a "real" SDR terminal sampling at RF is currently not feasible for any kind of commercial transceivers.

An alternative method shown in Figure 14 is only replacing all the dedicated hardware in baseband by software or configurable hardware since they are processing digital data. The RF front-end is still in ASIC design and the position of ADC/DAC remains. Usually a software-based baseband or reconfigurable hardware-based baseband would consume more power than an ASIC baseband.

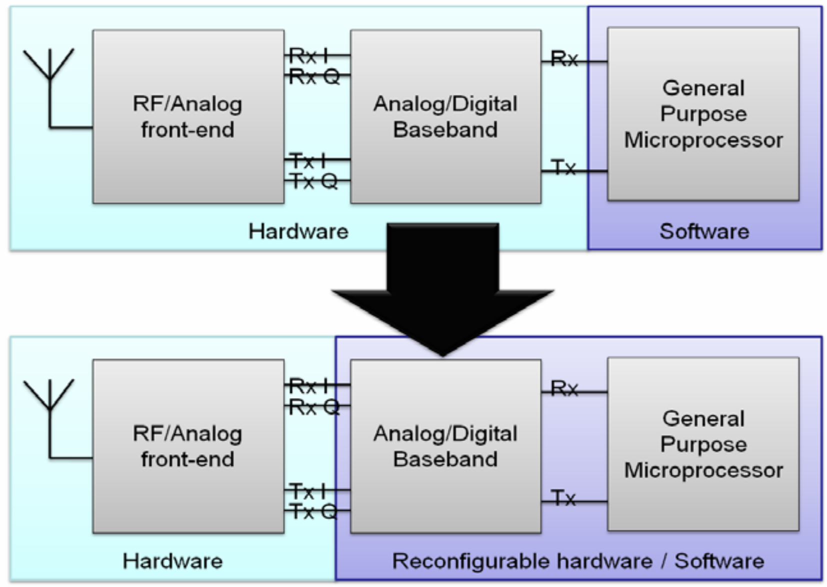

Figure 14: SDR system approach

In this terminal architecture, the reconfigurability is limited. The system can only operate in a certain range of frequency which the fixed RF front-end allows. But the encryption and modulation scheme may be updated (e.g., from GSM/GPRS to EDGE). Although reconfigurability is limited in baseband and upper layers, the modified system can be realized commercially today and in a very cost efficient way. The systems still have the benefits of fast-to-market because of the flexible baseband. It will require pre-installation of future RF front-ends if wanting to upgrade to other radio technologies. A software upgrade to a new radio technology operating in another frequency band, other than those supported by the installed front-ends, is not possible. This fixed front-end SDR solution is debated to provide sufficient reconfigurability for many needs, since the standardization upgrades of wireless technologies are mostly on radio modulation schemes[3] and the changing of carrier frequency bands[4] are comparably rare.

SDR is proposed being able to save hardware costs in the long-term. A simple demonstration showing the long term cost analysis of Bluetooth hardware can be found in Figure 15. The SDR application looks more expensive than the regular dedicated hardware-based application in the beginning. But when the radio technology upgrades were introduced they would only require a low cost software upgrade in reconfigurable radio solution. In a dedicated hardware-based radio solution, the hardware will have to be replaced at each upgrade, causing a higher total cost after just a few upgrades. Therefore SDR is saving cost in the long run, and is by all accounts the most suitable solution while developing telematics systems.

[3] Bluetooth 1.1, 1.2, 2.0 to EDR, GSM to GPRS, to EDGE, WCDMA to HSDPA
[4] Analog mobile to GSM, GSM to WCDMA, Bluetooth to UWB

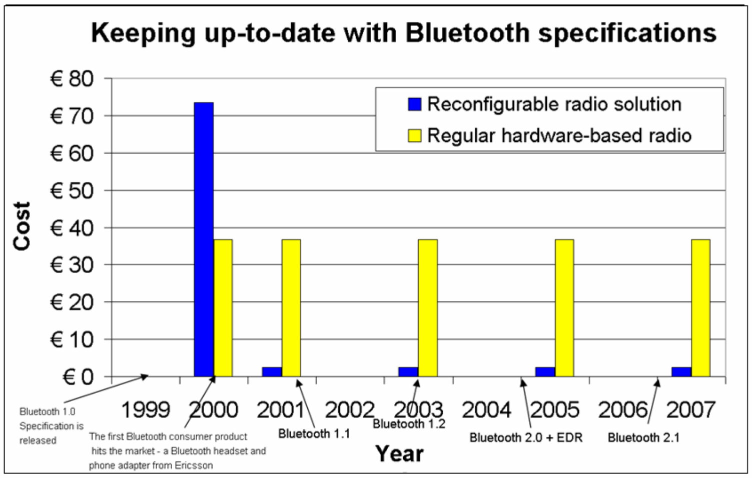

Figure 15: long tern cost analysis of Bluetooth hardware

Configurable front-end

If wanting to develop a completely reconfigurable SDR platform, the front-end issue will need to be solved. Two solutions can be taken into account: configurable front-ends and portable (exchangeable) front-ends. Both of them are exist in the market. However, the configurability of these configurable front ends is somewhat limited, and prices are also very high. Two solutions are introduced below but this report will not dig into this field.

The first low-cost, high performance reconfigurable front-end chip, Softransceiver, has been introduced by BitWave and is said to be capable of providing multi-band and multi-mode functions. Developers wanting to use this product would have to make sure about the compatibility with baseband and software protocols. Also some problems like the precision and requiring time of shifting the operation frequency as well as the capability of multi-task will need to be considered. The Softransceiver is quite new and its market availability has been delayed for several years.

There are some portable front-ends existing in the market. Most of them are GPS front-ends with USB interface for PC with navigation software. It is believed that USB2.0 would be the candidate for SDR telematics systems since it's universally used. USB2.0 can support up to 480 Mbps which is good enough for SDR, and moreover, the USB port can be used for connections to different electronic units. The two main issues, before the portable front-ends are seriously considered as an option of the SDR telematics systems, would be the integration with external antenna and the developments of new hardware of GSM/GPRS, wireless LAN (WLAN), Bluetooth portable front-ends.

4 Low cost solutions for eCall Devices

Module solution vs. chipset solution

When talking about dedicated hardware there are module solutions and chipset solutions. While they may provide the same basic radio function, they are substantially different. A chipset may contain full functions but cannot work by itself. Usually it needs external components like oscillators, memory and power management chips. Together with resistors, capacitors and inductor soldered on a printed circuit board (PCB) it becomes a module.

A module solution is usually more expensive than a chipset solution, but when looking at the cost of chipset solutions, the bill of material (BOM) and cost of development are also needed to be considered. Because the development cost is independent from the production volume, the volume should usually be more than a certain threshold, e.g., 100,000, to be cost beneficial when designing an own module from chipsets. If the volume is small, it's better to go for a system built up by modules.

Antenna

There are plenty of choices on GSM/GPS antennas. An external GPS antenna is most likely needed since the signal is rather weak, but the necessity of external GSM antenna will depends on where the eCall device is situated. If allowed, using patched GSM antenna can save around €7.5 ($10) per unit. But for this type of highly reliability dependent device, using both GSM and GPS antenna is safer. Using a combo antenna will save around €4 ($5) per unit [35].

4.1 Possible architecture

4.1.1 A. Chipset (shared microprocessor)

The concept is to use the same microprocessor to run both GSM and GPS protocol stacks. An illustration is shown in Figure 16. Because of the prosperity of the handset market, most GSM/GPRS chip providers have integrated chipset solutions or single chip solutions covering the whole GSM/GPRS functions including front-end, baseband and processor. Since the GSM L2/L3 protocols normally do not consume too many processing instructions on the microprocessor, the trend is to add the navigation control protocols into the same processor. Therefore GPS chip providers intending to reduce hardware (which is cost) are providing "hosted application" GPS chipset solutions. The GPS higher protocol stacks (acquisition control and navigation calculation) run on the GSM microprocessor. It requires only GPS front-end and baseband hardware, thus reducing the size. Some suppliers (e.g., RFMD) even have their own software-based solution, further reducing the hardware to merely a GPS front-end. The software-based solution may require more on the processor than just GPS controlling protocols since the GPS acquisition also runs on the processor.

In highly competitive handset market, GSM/GPRS chipsets are available at a low price. Hosted application GPS chipsets also helped reduce size of handsets. This type of architecture may require the lowest unit cost, but still, since it's built up by chips, it requires more efforts on developing the eCall device. The developer needs to design its own PCB board and on the cost it also needs to consider the bill of materials.

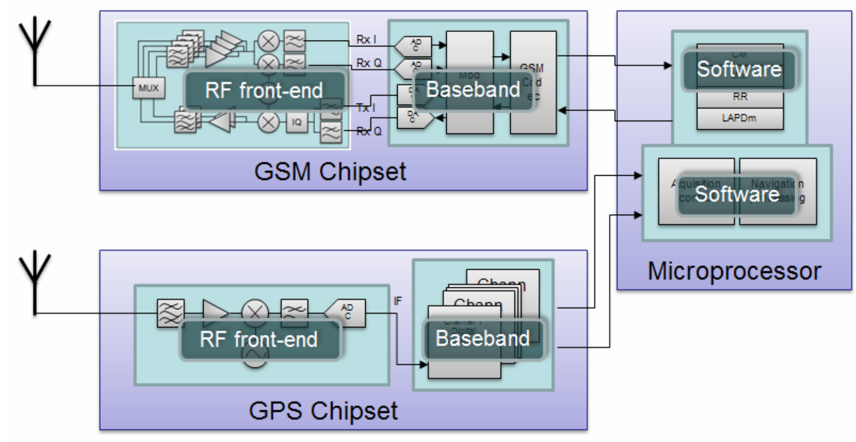

Figure 16: Shared processor + GPS front-end + GSM front-end

TI (Texas Instrument), Analog Devices and Infineon[5] provide integrated chipset solutions. TI and Analog Devices have many choices for different requirements on radio access technologies (GSM/GPRS, EDGE and WCDMA) and processors (basic phones, feature phones and smart phones). Both Infineon and Wavecom have their own single chip solutions. Infineon's E-GOLDvoice is the newest chip which integrates processor, front-end and power management. Partnered with Global Locate, Infineon provides handsets with A-GPS function which would be a good choice for an eCall device, provided that A-GPS would work in Europe – which it doesn't right now. Wavecom also provides its new product Wirelessprocessor (production in April 2007) which is a GSM/GPRS full function chip with high interoperability with Bluetooth and GPS (Wavecom has both the Bluetooth and GPS protocol stack solutions). For other radio accessibility it only requires radio front-end and baseband chips. The control protocol stacks can run on the Wirelessprocessor. This single chip targeting at M2M application also providing CAN bus control would be one of the choices for embedded eCall systems. The Wirelessprocessor does not include power management functions.

RFMD RF8110 is a software-based front-end working with RFMD's GPS software on host processor. Unfortunately, this low cost front-end chip will soon be out of product line. eRide working with Wavecom provides a GPS hardware reference design (including front-end and baseband) with the client's navigation software on host side. Global Locate's Hammerhead and Hammerhead II A-GPS ICs help Infineon provide small, low power solutions for handsets. GloNav's GNS4540 and NemeriX's chips are also hosted applications.

[5] All mentioned companies and products can be found in Appendix A

Reference pricing of selected chipsets is shown in Table 1.

GSM chipset	TI	TWL3016+TRF6151 (Baseband/Power + RF)	N/A
	Analog Devices	AD6548/AD6538 + AD6537/AD6535 (Baseband/Power + RF)	N/A
	Infineon	PMB7860+PMB6271+PMB6811/6814 (Digital + RF + power)	~ €7.5 ($10) module ~ €16.5 ($22)
		PMB7870+PMB6811/6814 (Digital&RF + power)	
		PMB7880 (Digital&RF&power)	
	Wavecom	Wirelessprocessor	€ 40
GPS chipset	RFMD	RF8110 (Software-based FE)	€3.2 ($4.3)
	eRide	Hardware Reference Design (ASIC RF + ASIC DSP)	€4.5 ($6) module €9 ($12)
	Glonav	GNS4540	$6
	Global Locate	HAMMERHEAD I & II, GL-LN22+GL-20000	N/A
	NemeriX	NJ1006A+NJ1030A, NJ1836	N/A

Table 1: pricing of chipsets

4.1.2 B. GPS full solution + GSM full solution

An easier way is to put together a GSM module and a GPS module. Both modules have their own full functions in GSM and GPS. Figure 17 is one example showing how this system will work as an eCall device.

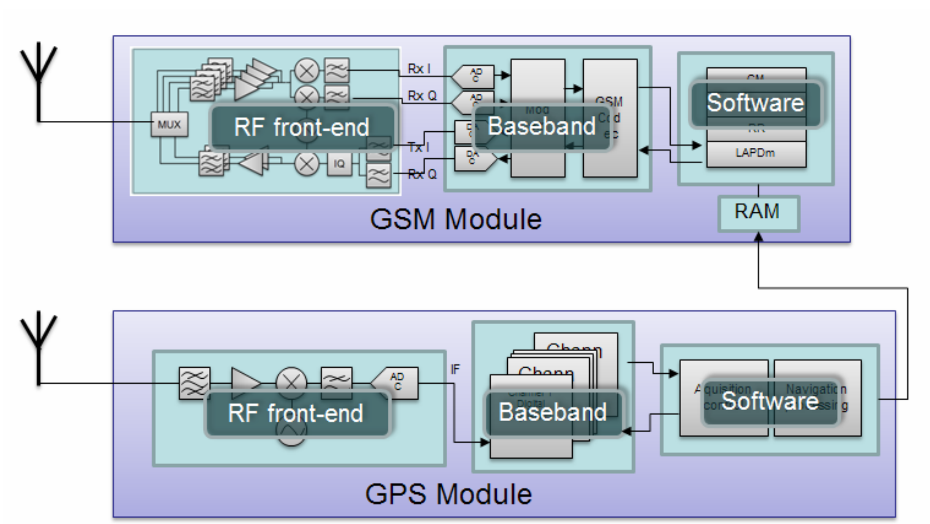

Figure 17: GPS full solution + GSM full solution

The GPS module is an independent GPS receiver and processor. It sends out NMEA[6] format data containing the calculated position information in period (ex, every

[6] NMEA stands for National Marine Electronics Association (protocol). It is a standard protocol defining how to transmit the GPS positioning data and the contents of the data.

second). The position information will be stored and kept updated in a random access memory (RAM) of the GSM module. When eCall triggered, the GSM module will send out the latest position data in the RAM. Normally the GSM modules are more functional modules which contain voice codec and multimedia functions. The voice in/out put and airbag, also including eCall button should be connected to the GSM module and controlled by the GSM module, so that there is no need for another control processor.

This is a rather easier solution to implement, but on the other hand will require the biggest PCB size and probably higher cost compared to a chipset solution or a combo module (in next section). Most of the GPS or GSM modules are in match box size.

Major GSM module provider Telit has a couple of choices for different applications. PYTHON allows customers to run their own code for a complete hardware solution. GE862 family has on-board SIM card holder. Other GSM module providers are Wavecom and Segem. The major GPS module provider is Trimble. The new Copernicus GPS module is the most recommended considering both size and cost. Other providers are many, GlobalSat, Falcom, Tyco electronics are some examples. A deserved to be mentioned combination is Telit GSM module GE864 and Tyco GPS module A1037-A with an extra microprocessor. This Telit's solution doesn't need connectors between modules and is only around €51.

When looking at complete GPS chip solutions it will definitely be SiRF. SiRF is the biggest GPS complete chip provider in the world. Many modules are labeled using SiRF's GPS chip. SiRFstar III is their newest product. Other companies like u-blox and u-Nav provides wide variety of products from RF chips, baseband chips to single chip solutions, and also for mobile applications.

Reference pricing of selected modules and chipsets is shown in Table2.

GSM module	Wavecom	Q2686H	€50
	Telit	GE862, GE863, GE864	€65, x, €40
	Seimens	AC45, MC family	N/A
GPS module	Trimble	Copernicus	€15 ($20)
	GlobalSat	ET-332, ET-312	€15 ($20), €15 ($19)
	Tyco	A1037-A	€7.5 ($10)
GPS chipsets	SiRF	SiRFstar III	€7.5 ($10) BoM + €3 ($4-5)
	u-blox	wide choices	N/A
	u-Nav	wide choices	N/A

Table2: pricing of GSM full solutions and GPS full solutions

4.1.3 C. GPS/GSM combo module

An illustration is show in Figure 18. Sensing the trend of combining GSM and GPS functions in telematics usage, some manufacturers are providing GSM/GPS combo modules. Because the module providers have integrated the GSM and GPS functions for the clients, the cost of one single module is not cheap. This type of eCall system should be the easiest implemented and still cheaper than the independent GSM and GPS module solution.

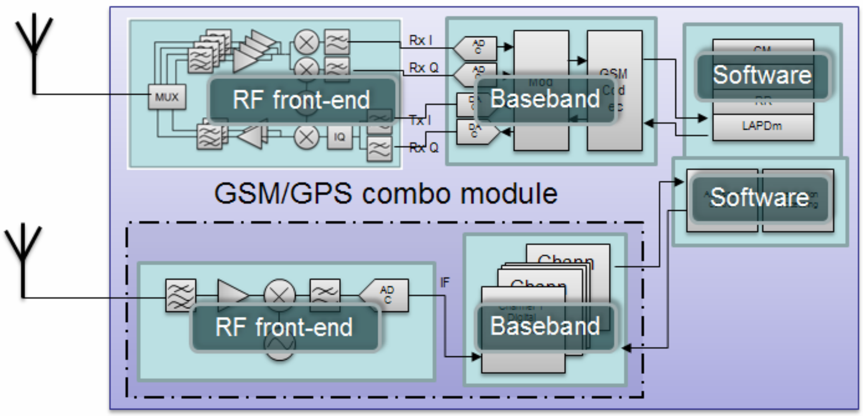

Figure 18: GPS/GSM combo module

Telit GM862-GPS and GM863-GPS are GSM/GPRS modules containing SiRFstar III chip, GM862-GPS has integrated SIM-card reader. Siemens provides three types of GSM/GPS combo modules controlled via AT commands. The main issue for the eCall application is that the operating temperature of Siemens' modules is only -20~+70 °C, which might not meet the requirements of in-vehicle applications: -40~+85 °C.

Reference pricing of selected combo modules is shown in Table 3.

GSM/GPS combo module	Telit	GE863-GPS, GE862-GPS	x, €59
	Siemens	XT55, XT65, XT75	N/A

Table 3: pricing of GSM/GPS combo module

4.2 Summary

For low cost eCall device design, there are two main categories: chipset solutions and module solutions. Chipset solutions are usually cheaper than module solutions in high-volume as discussed above. Therefore, targeting in high quantity as an eCall device, manufacturers should go for chipset solutions and design their own eCall module. But the development of an own module would need more time thus would run on a higher risk of getting obsolete when the products come out. While the eCall standards are still unclear, a module solution may be a safe option in the trail stage, and would cost less if in small quantity. If using a module solution, GSM/GPS combo modules generally cost less and are more easily implemented than two individual modules.

While adding positioning functions into mobile phones is the new coming trend, many mobile phone chip manufactures have been cooperated with GPS chip manufactures. According to Infineon, a GSM/GPS solution would cost approximately €22.5 ($30), including all enclosures (i.e. a module). It's foreseeable that cooperation between automotive manufactures and mobile phone manufactures can bring a low cost eCall solution that is under €50. A possible solution is a standalone eCall box without integration to the vehicle. It does not seem to conflict with the recommended eCall specifications. This kind of eCall box may be hidden inside the vehicle with basic eCall functions and its own voice interface and buttons. The sensor of automatic trigger could be a speed sensor.

An overall pricing of module/chipset designs is shown in Table 4. The antennas, battery and power supply are the same for every solution. Among these, chipset solution would require the most in enclosure and combo module solution would require the least.

Component	A. Chipset	B. GPS module + GSM module	C. Combo module
GSM chipset	€15	0	0
GPS chipset	€5-7	0	0
GSM module	0	€40-50	0
GPS module	0	€10-15	0
GSM/GPS module	0	€0	€59
GSM antenna	€5	€5	€5
GPS antenna	€4	€4	€4
Power supply	€5	€5	€5
Battery	€6	€6	€6
Enclosure (connector)	€15	€10	€5
Total	€55 – 57	€80-95	€84

1 US dollars = 0.75 Euro

Table 4: overall pricing of module/chipset designs

5 SDR solutions for eCall Devices

Software/reconfigurable GSM

GSM L2/L3 protocols normally run on a microprocessor. Among them, the advanced RISC machine (ARM) processor has been adopted by many handset manufacturers. One software GSM company has speech codec on ARM processor which is an improvement of saving hardware because the ARM processor can run both the L2/L3 protocol layers and the speech codec at the same time.

In software GSM, most of the GSM/GPRS physical layer can be implemented in a strong DSP (e.g., TI C55) covering time and frequency synchronization, modulation/demodulation and encryption/decryption. Software GSM/GPRS baseband providers only have pure digital solutions, so that the RF front-end has to come from another supplier. In order to work with the RF front-end, a RF interface to control the specific front-end has to be implemented in the hardware, which has to go for FPGA if one wants reconfigurability. Also, since DSP is not fast enough to handle real-time processing of GSM/GPRS signals, a RAM is needed for buffering between the RF front-end and the DSP. There are two methods to realize the RAM. As shown in Figure 19.a the first method is to use a real RAM between RF front-end and DSP processor, then use a small FPGA to implement the RF interface, hence a dual-port RAM which can be accessed by the FPGA and DSP is needed. The second method shown in Figure 19.b is using the FGPA to implement the RAM. This FPGA would need to implement the RF interface, RAM and the memory interface to DSP and would require much more logic gates.

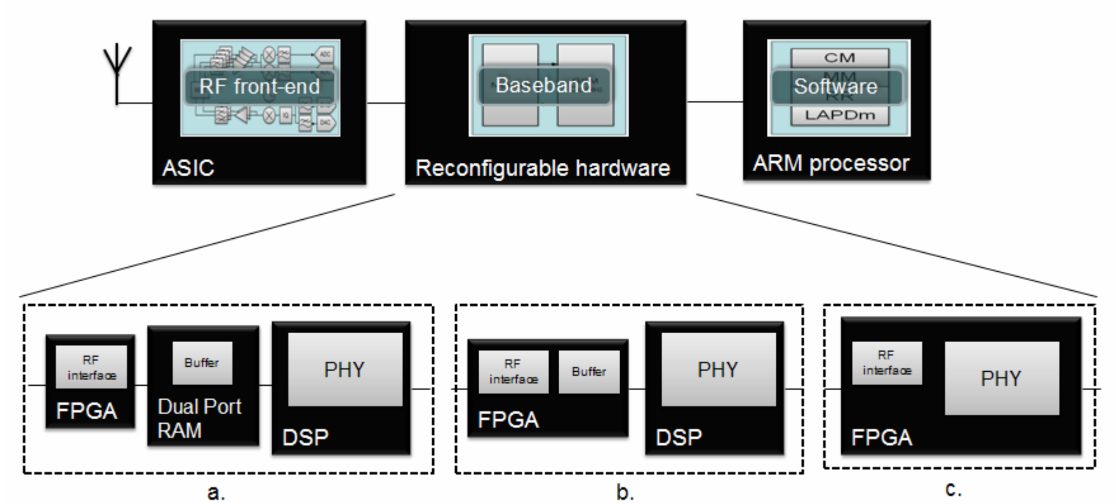

Figure 19: Software GSM

Another approach shown in Figure 19 c. is to keep the physical layer in hardware but in a FPGA so the system can still keep its reconfigurability. Since the hardware PHY on FGPA is fast enough, there is no further requirement of RAM but a RF interface is still needed. The good news is that the DSP can be eliminated from the system and therefore reduce the hardware. Since the hardware requirement has been reduced to only a FPGA and an ARM processor, Xilinx's new technology of adding PowerPC into FPGA makes it possible to implement GSM baseband and L2/L3 layers and even GPS solution into one single chip, shown in Figure 22.

Software GPS

The software GPS receiver shown in Figure 20 a. normally means the acquisition is done in a DSP or microprocessor excluding the FPGA approach. By replacing the digital hardware processing by software, software acquisition is benefited from utilizing fast Fourier transform (FFT). The FFT method searching in frequency domain to find the satellite signals is more efficient and can accomplish weak signals acquisition more effectively than massive parallel correlation. In hardware it would require tens of thousands of correlators and frequency lock loop (FLL) feedback in time domain in order it solves the Doppler shift problem [36].

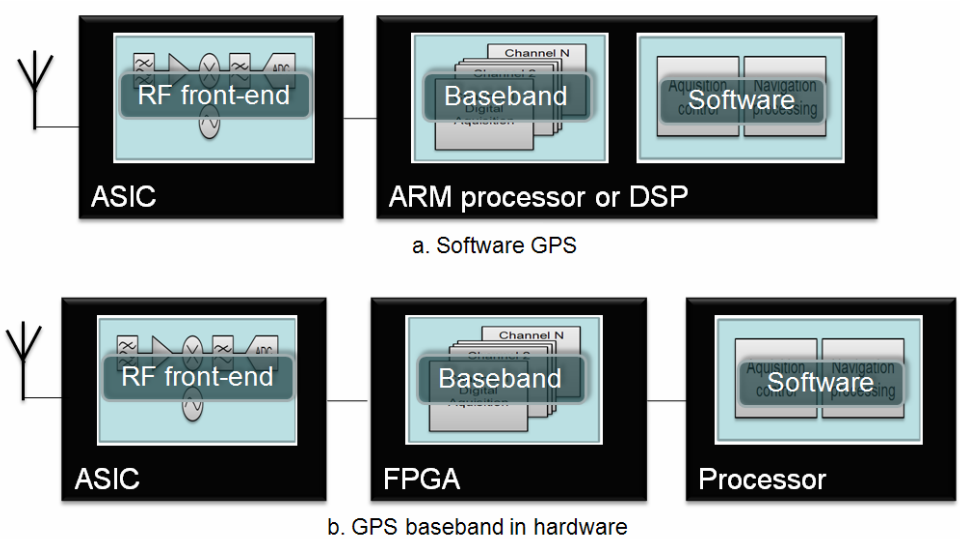

Figure 20: Software GPS

Even though DSPs emphasize on DFFT, meaning it performs faster in DFFT when compared to correlation, software acquisition using DSP can still run correlation. As shown in Figure 20 b., running ASIC IP cores on FPGAs can still be considered a type of SDR because FPGAs are "software reconfigurable". To run correlation for acquisition, ASICs are the fastest, followed by FPGAs, then DSP. Compared to correlation, DSP is better at FFT in which acquisition can even has an equal performance as massive parallel correlation in ASICs.

Software GPS receiver is not a new term and actually quite a few companies have their own software-based GPS solution, but most of them are sold with specialized GPS front-ends as a complete solution and may not work with other GPS front-ends. Still, this type of software-base GPS solution only allowing limited software reconfiguration for clients would not be a choice for our SDR platform. The companies that truly provide GPS IP source code are Nordnav, SPIRIT and SoCsolutions.

Nordnav was the first company to release a commercial software GPS solution. After emerging Nordnav Technology AB and Cambridge Positioning Systems Ltd, Cambridge Silicon Radio (CSR) planed to provide an extremely low cost location solution for handsets. Targeting at providing GPS solution less than $1 when using its Bluetooth chip, CSR expects to offer its first GPS product during the first half of 2007 [37]. The software-based solution supporting ARM 9, 11 and various processors requires no further hardware beyond a RF front-end.

SPIRIT provides embedded voice, audio, video and data communication software products and consulting service. Spirit provides full complete IP core of their software GPS solution on DSP C55 or C64. The services include hardware design, software IP code releasing, and consulting service after the product is done.

SoC Solutions provides GPS IP design solutions for ASICs and FPGAs. Its FPGA IP solution can be a choice of SDR design in Figure 20 b. The IP core requires approximately 6,500 ASIC logic gates per channel, which means a 20 channel capacity will consume around 130,000 logic gates. This design is only a baseband hardware design and doesn't include software in processor.

Front-end

The choosing of GSM front-end seems trickier than choosing a GPS front-end. So far, two software GSM providers have claimed to work with specific RF front-ends and it is not sure if their software solution can cooperate with other RF front-ends. GPS front-ends, on the other hand, are easier to find. Even though both SPIRIT and Nordnav have used some certain RF front-ends on their own reference solutions, both of them claim that their software solution can cope with many different basic GPS front-ends.

Reference pricing of selected front-end is shown in Table 5.

GSM FE	RFMD	Polaris 2 Total Radio Module (RF6026 + RF3178)	€5.2 ($7)
	Skyworks	SKY74137 + SKY77331	N/A
	Analog Devices	AD6548	N/A
	Aero+	RF transceiver, Si4200, Si4201, Si4134T	€4.4 ($5.8) [38]
GPS FE	SiGe	SE4100L	€1.4 ($1.8)
	NEC	UPB1009K	N/A
	GloNav	GNR1040	€1.2 ($1.63)

Table 5: Pricings of front-end suitable for SDR applications

Open multimedia applications platform (OMAP)

Since both DSP and ARM are needed, Texas Instrument's OMAP would absolutely be considered as the best choice. Targeting at feature phones, multi-media and smart phones, TI's OMAP platform is composed by an ARM processor, a DSP subsystem, internal SRAM, memory traffic controller and shared peripherals for multimedia applications. Using ARM for operating systems (OSs) and DSP for media processing, OMAP can bring eCall device a lot more multimedia capabilities while still providing communication operation. Applications supported by OMAP platform include Bluetooth, WLAN and GPS, as well as display control, keyboard, camera, PC and memory card interfaces.

Field programmable gate array (FPGA)

FPGA became an option for SDR solutions because of its re-programmability. A FPGA is an integrated circuit that contains programmable logic components and interconnections which can duplicate the basic logic gate (AND, OR, NOT, XOR) and some even more complex functions.

FPGAs are widely used in the industry during the developing stage before mass production of ASICs. Compared to ASICs, FPGAs are generally slower and drawing more power. They, also come at higher cost. Nowadays, by technology improvements, FPGAs can handle more complex functions and higher speed, as well as reducing the cost in large quantities. But the price grows exponentially versus the chip size because the yield rate decreases while making lager size ICs in a wafer, hence the large size FPGAs are still considered expensive. FPGAs are currently not suitable for handheld terminals because of the high power consumption and their high costs, but may be acceptable in embedded systems for vehicles.

FPGAs can be merged or divided for different needs. If two FPGA cores run on the same hardware structure, they can be put together into a larger FPGA if it has enough number of logic gates and I/O ports and processing speed. On the other hand, if a FPGA core allows partition, it can be divided into some (more than two) smaller FPGAs. If a FPGA is used, it's better to implement the physical layer in the FPGA instead of in a DSP. A FPGA can be used to implement the whole DSP but this is rather a complicate task and the DSP core will have to be rewritten, therefore it is not a good choice.

5.1 Possible architecture

5.1.1 A. OMAP + FPGA

By simply fulfilling the requirements on software (DSP and ARM) and digital hardware (FPGA), OMAP plus FPGA is definitely a sufficient solution without any integration problems. This is illustrated in Figure 21. In OMAP series the OMAP59xx, OMAP16xx and OMAP17xx are equipped with ARM9 and DSP C55x, and OMAP2420 is with ARM11 and DSP C55x. GSM/GPRS software usually supports ARM9, 11 for L2/L3 protocol software and DSP C55x for the physical layer software. Nordnav's software GPS solution supports ARM9, 11 and SPIRIT supports DSP C55x and C64x. While the GSM software has been deployed, developer can choose either ARM or DSP depending on which one is available. ARM9 and DSP C55 are overqualified to the L2/L3 and PHY performance requirements of software GSM/GPRS. Therefore, most probably software GPS would easily run on either in ARM or DSP.

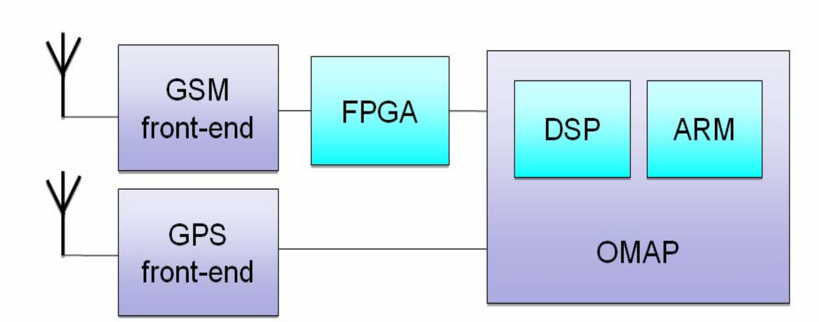

Figure 21: SDR FPGA + OMAP

OMAP59xx are ideal for portable data terminal applications [39] and in an acceptable price range. Compared to the GSM chipset solution it is more expensive but contains more multimedia capabilities. Other OMAP platforms (OMAP16xx, 17xx, 2420) are sold for wireless manufacturers in high-volumes, so they are not available for pricing from distributors but are assumed to be in the same price range.

The FPGA is needed but if the physical layer runs on DSP, the required logic gates in FPGA would be much less than the signal FPGA solution (in next section), so a smaller FPGA can be used. For the solution in Figure 19.a, Xilinx's Spartan-3E XC3S500E with 500k logic gates would be enough for the RF interface but a dual port RAM may be expensive. Spartan-3E XC3S1600E for the solution in Figure 19.b would be a better choice.

While it is believed that OMAP and FPGA are overqualified for the eCall application, this architecture allows other future applications like multimedia and also other radio application like Bluetooth or WLAN. This SDR solution would be a suitable choice for implementing telematics devices for high-end vehicles that provide multiple services.

Reference pricing of selected OMAPs and FPGAs is shown in Table 6.

ARM + DSP	TI	OMAP5912	€15 ($20)
		OMAP16xx, 17xx, 2420	N/A
FPGA	Xilinx	XC3S5000 (Spartan-3)	€37.5 ($50)
		XC3S1600E, XC3S1200E, XC3S500E (Spartan-3E)	€7.5 ($10), €6 ($8), €4 ($5)

Table 6: Pricings of OMAP and FPGAs

5.1.2 B. All-FPGA

As shown in Figure 22, the single FPGA solution will have the GSM PHY implemented on FPGA and the L2/L3 layers run on a PowerPC. Since software GPS has to run on a PowerPC it will most likely have to be from Nordnav (of which the software runs on RISC processor). In those FPGA with PowerPC processor blocks which fits the logic gate requirements of physical implementation of one software GSM provider are Virtex-4 XC4VFX60 and XC4VFX100. It is believed that there would not be a big problem to run GSM and GPS software on the same processor if its speed is fast enough. The multitasking and interrupt can be handled by an operating system (e.g., Linux) which will spend some processor instructions as well. To be safe, GSM and GPS software can run on two separate PowerPCs since all the FPGAs on the list have two PowerPC blocks.

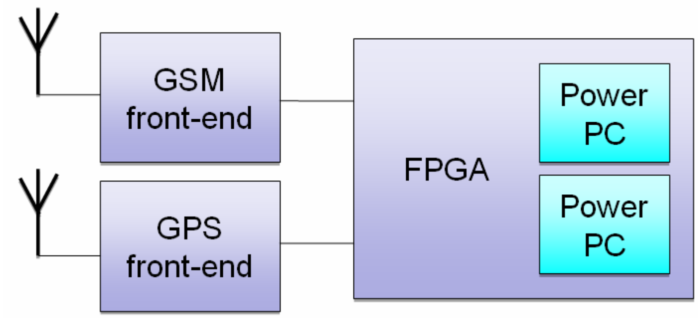

Figure 22: Single FPGA solution

If wanting to save the processor for other use, another choice is to implement GPS baseband acquisition on a FPGA (e.g., from SoCsolutions), but the control software then needs to be from another provider. The integration of GSM and GPS PHYs would not be a problem if the overall space, number of I/O ports and speed of the FPGA were enough.

The Single FPGA solution would be a feasible choice as a reconfigurable platform for eCall or other telematics applications but the price is too high. Xilinx's Virtex families are high performance and high-priced FPGAs that are not sold in high volume (10k is normally estimated as a high volume for this device). In a higher volume, say 100k, the price could probably go down about 50% but still it is too high for an eCall application.

Xilinx's Spartan FPGAs and the embedded microprocessor MicroBlaze could be a low price option. However, the biggest one in the Spartan-3 series, XC3S5000 with 5 million gates, can barely meet the hardware requirement of GSM PHY. Consequently another FPGA would be needed to implement the microprocessor - MicroBlaze. An illustration of this solution is in Figure 23. In this solution two MicroBlazes are needed, one for GSM L2/L3 protocol and one for software GPS. The most economical way is to use Spartan-3E XC3S1200E, but the MicroBlazer processor is perhaps too weak for GSM and GPS baseband implementations. Another issue is that XC3S5000 is still too expensive. A cheaper solution is to use three XC31600Es for the GSM physical layer, but the risk is that the GSM PHY core does not allow to be partitioned.

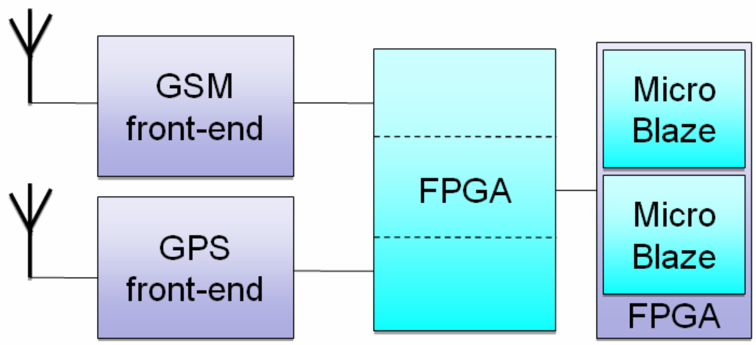

Figure 23: Separated FPGAs solution

Reference pricing of selected FPGAs is shown in Table 7.

FPGA	Xilinx	Virtex-4 XC4VFX60, XC4VFX100	€64 ($85)*, €97.5 ($130)*
		Spartan-3 XC3S5000	€37.5 ($50)*
		Spartan-3E XC3S1600E, XC3S1200E	€7.5 ($10), €6 ($8)

* 50% of the price in 10k.

Table 7: Pricings of FPGAs

5.2 Summary

While microprocessors and DSPs still cannot catch up with the processing speed of hardware, FPGA seems like the essential solution for a SDR approach. By keeping Reconfigurability, FPGAs still possess the high speed feature of hardware implementations.

In the SDR approach, the OMAP+FPGA solution, realizing most GSM PHY layer in the DSP of OMAP, is capable of providing more radio and media functions. As a solution for telematics and infotainment devices, it has comparably cost low. This shows that a reconfigurable wireless platform does not always have to be expensive. The pure FPGA solution is not recommended as the single FPGA solution is still too expensive. The cost of the separated FPGA solution is acceptable but it may not meet the performance requirements. Maybe in the near future the price of high performance FPGAs will decrease so the SDR application can be more possible.

An overall pricing of the SDR design alternatives is shown in Table 8. While manufacturers are looking at a SDR approach, the software royalty and the upgrade service behind the license should not be neglected. Also, in these solutions, there is a need for a GSM front-end and a GPS front-end. The rest are basic components that are needed in all kinds of eCall solutions.

Component	A. FPGA + OMAP	B. FPGA (single FPGA)	B. FPGA (separated FPGAs)	B. FPGA (separated FPGAs)
Processor	€15	€100 [i]	€6 [ii]	€6 [ii]
Baseband	€7		€38 [iii]	€23 [iv]
GSM front-end	€5	€5	€5	€5
GPS front-end	€2	€2	€2	€2
GSM antenna	€5	€5	€5	€5
GPS antenna	€4	€4	€4	€4
Power supply	€5	€5	€5	€5
Battery	€6	€6	€6	€6
Enclosure (connector)	€15	€10	€13	€15
Software Royalty	€10	€10	€10	€10
	€74	€147	€94	€81

[i] Virtex-4 XC4VFX100, [ii] Spartan-3E XC3S1200E, [iii] Spartan-3 XC3S5000, [iv] Spartan-3E XC3S1600E * 3

Table 8: Overall pricing of SDR design

6 eCall discussion

6.1 eCall device cost analysis

For the market of low-end cars, the eCall device should target large volumes but only with the basic eCall function. The cost is indeed the key factor. This type of eCall device should cost as little as possible. The eCall device could be a standalone system with its own control interface (e.g., buttons). It would not even need to communicate with the vehicle, which would save a lot of money. The reconfigurability may not be very important since the life time of an old car is predicted not to be long in any case.

From the cost survey above, an integrated and low cost eCall solution under €50 does not seem to exist. If it is including the costs of vehicle integration (~ €10) and SIM card management device (~ €10), the costs for the manufacturers will probably be around €70 for chipsets solutions and €100 for module solutions. For a standalone eCall only device (No SIM card and no vehicle integration) with patched GSM and GPS antenna on PCB board, the cost might be reduced to €50. However, there are still many problems which will be discussed in 6.2.

While looking at the SDR approach, the OMAP+FPGA solution is still the least expensive since pure FPGA solutions are not ready yet. In addition, the OMAP+FPGA solution provides more advantages such as reconfigurability, multiple radio accessibilities and multi-media functions. For these merits with €10-20 more cost, OMAP+FPGA is the best choice for manufacturers who want to integrate eCall with other telematics functions which would target high-end cars or trucks. In high-end cars, since an eCall device requires GPS and GSM connectivity, it would be a big plus if the same hardware can provide navigation and real-time data connection service. Combining an eCall device with other wireless technologies like Bluetooth or WLAN integrated in the high-end vehicles, the telematics device could provide drivers safety and infotainment services.

At the starting point of developing an eCall module, a large amount of investment is needed. The module approach of low cost solution may cost less at the beginning, on the other hand the chipset solutions and SDR design would cost a fortune in the start-up phase. But if looking in the long-term, it could be different. Below is a pricing analysis for three cases: SDR approach, chipsets approach and module approach. The development costs are fixed and independent of the product volume. As in Figure 24, we can see that while the product volume exceeds 100k, the unit cost will be near the material costs and the development cost is also comparably smaller. Assuming that a certain type of telematics device (eCall) is sold at the amount of 100k per year, how do we make sure the same device can still be accepted after 5 years? Here the SDR solution shows its advantages again.

Development costs	SDR	Chipset	Module
R&D (20 vs. 8 employees in 1 year)	1200	1200	480
Development tools and test environment	100	100	80
GSM software licenses	100	0	0
GPS software licenses	100	0	0
	1500	**1300**	**560**

Manufacturing costs (per k units)			
Bill of Material (BOM) + PCB	64	55	85
Royalty	10	0	0
	74	**55**	**85**

Unit: k€

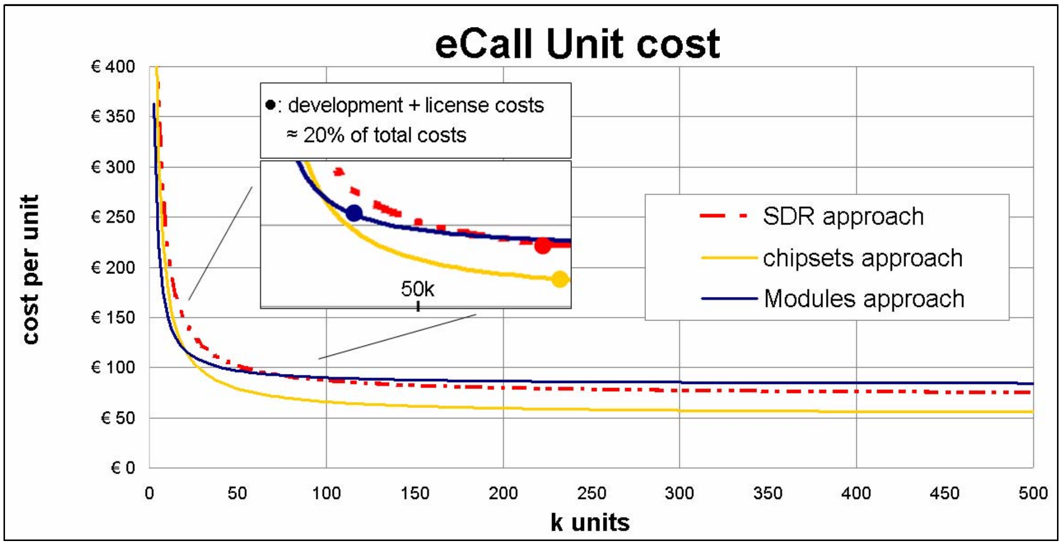

Figure 24: eCall unit cost analysis

6.2 eCall business cases

It is foreseeable that eCall will bring a great market for its stakeholders within the automotive industry, the mobile telecommunications industry, insurance companies, public emergency authorities and public social security organizations. But the overall business case for eCall is still quite unclear. According to a survey conducted by Nokia Automotive, Vehicle owners are only partly interested in eCall [40]. The automotive manufacturers also have stated that eCall will probably not generate any profit for them [41]. Telecom and insurance companies do not see much profit in eCall either. But despite the questionable profit for some of the involved parties, eCall is expected to save up to 2,500 lives and €2.6 billion per year in the EU, bringing the most benefits to the public sector [4].

The business for integrated eCall systems can be mainly categorized into two types: 1.Basic system for low-end cars and 2.multi service system for high-end/commercial cars. Some other solutions like standalone systems and nomadic systems are currently being discussed as well. In some ways, eCall can be seen as a telematics device.

6.2.1 Basic system for low–end cars

For integrated basic systems, both insurance and telecom companies do not see a profit from a non-commercial SIM card solution. "Crash notification" (eCall function) may give insurance companies some business but "Tracking and Tracing" (T&T) and "Pay as you drive" (PAYD) are the major business for them. The non-SIM or eCall only SIM systems will not provide real-time information for the later two services, hence will not give insurance companies productivity gains, and to telecom companies there won't be any commercial calls, not to mention the fact that emergency calls are free of charge [41].

The cost of an integrated basic eCall device is estimated around €100-150, which is twice higher than what is expected according to auSystems. The vehicle manufacturers have carried out their own research and found that savings are much lower than expected. Vehicle customers are not willing to pay for such a hypothetical service, and would rather choose metallic paint or accessory options. The public sector would receive the most benefit which is enough to cover the costs of the eCall development. There would be a need for public funding for the ramp-up period though [41].

A standalone solution would be the least expensive one, but the mobile phone manufacturers will then dominate this business. The eCall box manufacturers may be involved for system installation including the eCall box itself, control and voice interface and antenna. This can generate some profit but not much. Still, this kind of device are not crash resistant, which may bring slightly more business to the manufacturers. This solution requires a close cooperation between automotive industry and mobile phone industry, which is quite hard because the handset chipset manufactures will have to keep providing the same product over a long period of time but in small volumes. Of course, the product has to fulfill the requirements of automotive ECU applications, which is another obstacle of the cooperation.

6.2.2 The multi service system for high-end cars or trucks

A multi service system would bring more profits to all stakeholders. It could be a telematics system or a navigation system that provides eCall service as an add-on. Navigation services are indeed the most popular options for customers [40], but the penetration of embedded navigation systems is estimated not to exceed 2% and the price is high since an embedded screen is usually needed [41]. The manufacturers will have to introduce more affordable solutions.

Although GSM seems to be a logical choice for eCall application by its high coverage in Europe, it also will most likely be adopted by PSAP for a certain period, a system compatible with EDGE or UMTS would probably need to be taken into consideration. A service with higher data rate can generally generate more profit. To trucks, the tolling system, T&T and fleet management are important and surely will bring more profit. Vehicle manufacturers would attract more customers by providing more functionalities and aftermarket services. Insurance and telecom companies would also profit from the real-time information and higher data throughput as mentioned above [41].

Telematics is competing to some extent with the handsets market and is a weaker player economically. Compared to telematics, the handset market are much bigger and usually draw more attention. In the very near future, handsets will start providing navigation services. This is undoubtedly a challenge to telematics systems like eCall. On the other hand, it shows that the technology of combining mobile communication and positioning service has become more mature, and while large handset developers involve themselves into this market, the costs of this type of device will decrease too. But automotive industries will always find themselves behind the handset industries.

Even though there is plenty of demand for telematics services, most of the automakers do not persuade it but focus on other things like retaining or regaining market share and profitability because they didn't recognize the competitive advantages of telematics. Telematics also has its two main issues; one is that the M2M product life times are much shorter than the life time of automotives which last around 15 years. Keep telematics technology current and updated in older cars is a challenge. The second issue is that the whole telecom market is driven by billions of handsets worldwide. The millions of automotive M2M devices are easily neglected [42].

6.2.3 Nomadic solutions

The solutions are most like to be mobile phones but the nomadic navigation devices can work too. The mobile phone based solutions are said to be beneficial to the customers (convenient usage) and telecoms (potential additional airtime), also creating some positive revenues for the mobile phone manufacturers. The automotive industry would only need to develop the mobile phone interface and the embedded systems would therefore be smaller, but might lose the profitable hardware business. To insurance companies, the applications are limited, and therefore not very profitable. To the public side, the biggest issue would be the reliability of the handset devices [41]. It is required of the driver to bring the device, and there is a risk for incompatible device and also the fact that the devices are not crash resistant [5].

6.3 Private services related to eCall

The eCall technology already exists in the automotive industry. However, most of them are more comprehensive systems than eCall and provided as a private service, without any compelling legislation. These telematics devices are provided by third party manufactures and only sold in some certain car brands. Since the PSAPs have not been integrated completely, emergency services are provided by other private service centers. Therefore the profits are shared by three parties: vehicle manufacturers, equipment developers and the service providers, which is the main reason for causing customers high price to install the systems. At the starting point, most vehicle manufacturers are providing their telematics systems as optional equipments to new cars. If to be sold with new cars, the installation price would be more easily accepted by customers.

The telematics service with emergency call function has achieved the biggest success in North America. The world's leading provider of telematics services, OnStar have more than 4.5 million subscribers mainly in the US. The telematics system OnStar is now (2007) a standard equipment of all General Motor cars in North America. The system simply consists of a GPS module and a mobile communications module together with a three button interface, but OnStar can still provide a comprehensive subscription-based service merely through voice calls. The system supports both advanced mobile phone system (AMPS) and CDMA to communicate with OnStar representatives [43].

BMW, Fiat Auto and PSA Peugeot Citroën have introduced their multi services systems. All three systems are equipped with a GPS module, a mobile phone module and a display for traffic direction services. When emergency call triggers, a voice connection will be established between the service center and the driver. Although the functionalities of the three systems are basically similar, the telematics services behind the systems are differentiated by different providers. BMW's Connected Drive with ATX service gives the most comprehensive service but is only available in three countries within Europe [44]. Fiat Auto's CONNECT system [45] and PSA Peugeot Citroën's RT3 or NaviDrive system [46] are from the same system developer but with different services providers [47].

Jaguar Watch/Land Rover Watch and Volvo On Call systems are categorized into integrated basic eCall systems. The Watch system should be capable of providing emergency calls, nevertheless, the service provider EuroWatch does only provide stolen vehicle tracking service, but with the widest coverage of 33 countries in Europe [48]. Among the existing eCall compatible systems in Europe, Volvo On Call is most similar to GM OnStar. Volvo On Call requires the lowest installation fee but still provides telematics services including emergency call through 14 countries in Europe, and with expansion plan of 2 to 4 countries per year [49].

7 Conclusion

It is clear that eCall is an irresistible trend by seeing the fact that many automotive manufacturers have started to deploy their territory in emergency service market and some countries have adopted aggressive plan on eCall. The price of an eCall device is still very high and there is not much motivation for customers to buy it. In order to make eCall widespread in Europe, a low cost eCall solution with a firm legislation, or providing it together with a multi service package that makes customers feel that eCall is worth the money, would be needed.

A low cost eCall system at around €50 can be achieved by applying integrated chipsets in a standalone device. This will require a well founded cooperation between the eCall box manufacturer and the handset module manufacturers, to ensure the availability over time. A fully Integrated PSAP system also needs to be achieved in order to bring customers a low priced service, which will be acceleration to this low cost solution as well.

GSM and GPS are still the best choices for the eCall application. Galileo is not sure to be launched in time but still, it is highly possible to become an eCall requirement, therefore the compatibility of Galileo is worth consideration and it actually will not increase too much of the cost. With GPS host applications an eCall device can save the need for hardware thus reduce the cost. In the future it will perhaps also have the capability of A-GPS functions. Software GPS can bring lots of benefits even just for basic eCall solution. It can save even more cost than GPS host applications and will be easier to add Galileo services in the future. Most of the GSM solutions are already including GPRS. EDGE could be beneficial as it provides a faster data service but this service is actually not necessary for eCall applications.

The multi service systems compatible with eCall functions are a new trend of the automotive industry, and manufacturers benefit from more profitable businesses. The SDR approach would be an improved wireless solution for these systems. According to the research above, the cost is not more than a module approach which is adopted by most existing telematics systems. The FPGA+OMAP solution would cost around €100 and its benefits are promising in a total cost and life cycle view. The only obstacles are the high entry investments and the risk of incomplete reconfigurability but they are actually acceptable.

While looking at the SDR solutions in general, commercial software GPS baseband has been developed by several companies, and can be easily found. GSM baseband, on the other hand, is still not complete in software, some hardware is still required but it could be FPGAs. The configurable front-ends or portable front-ends are still not commercially practical but should be available in a few years to give a fully reconfigurable wireless system.

We can see that eCall is an opportunity to make the automotive industry realize the demands of telematics services. When developing a SDR telematics system, the automotive industry has to be a pioneer at this time, and not as usually, a follower in the wireless business. There are real economical reasons to employ SDR for telematics devices, when looking over time. SDR technology may not yet be suitable for the mobile phones but it is beneficial to terminals providing telematics applications. While the mandatory eCall launched in Europe, pushed carmakers to face the demands of telematics, and subsequentially started developing telematics systems, the automotive manufacturers should also see the advantages of SDR before it is too late.

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Appendix A
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http://www.bmw.com/com/en/index_narrowband.html?content=/com/en/insights/technology/connecteddrive/overview.html

CSR / GPS (Nordnav solution)
http://www.csr.com/gps/index.htm

eRide
http://www.eride.com/what/what.htm

EuroWatchCentral Limited
https://www.eurowatchcentral.com/

Global Locate Inc.
http://www.globallocate.com/SEMICONDUCTORS/SEMI_MAIN_Frameset.htm

GlobalSat / GPS engine board
http://www.globalsat.com.tw/eng/product_029_00002.htm

Glonav / Product
http://www.glonavgps.com/products.htm

Infineon Technologies AG / GSM/GPRS product
http://www.infineon.com/cgi-bin/ifx/portal/ep/channelView.do?channelId=-72346&channelPage=%2Fep%2Fchannel%2FleafNote.jsp&pageTypeId=17099

Magneti Marelli Holding S.p.A. / Telematics
http://www.magnetimarelli.com/business/businn.htm

NEC
http://www.necel.com/index.html

NemeriX / Solutions
http://www.nemerix.com/products/index.php

RFMD
http://www.rfmd.com/

Round Solutions
http://www.roundsolutions.com/

Seimens / Modules & Terminals
https://pia.khe.siemens.com/index_wireless_modules.modules_terminals-14200.htm

SiGe / SE4100L
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SiRF / SiRFstarIII
http://www.sirf.com/products/gps_chip.html

Skyworks
http://www.skyworksinc.com/

SoC Solutions / GPS solutions
http://www.socsolutions.com/web_pages/gps_solutions.htm

SPIRIT
http://www.spiritcorp.com/

Telit / Modules
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Texas Instrument / OMAP platform
http://focus.ti.com/general/docs/wtbu/wtbugencontent.tsp?templateId=6123&navigationId=11988&contentId=4638

Texas Instrument / GSM products
http://focus.ti.com/general/docs/wtbu/wtbugencontent.tsp?templateId=6123&navigationId=11964&contentId=29961

Trimble / Copernicus GPS receiver
http://www.trimble.com/copernicus.shtml

Tyco Electronics / GPS modules
http://www.tycoelectronics.com/gps/modules.asp

u-blox
http://www.u-blox.com/

u-Nav
http://www.unav-micro.com/

Wavecom
http://www.wavecom.com/

Xilinx / FPGA
http://www.xilinx.com/products/silicon_solutions/fpgas/