Modeling and Characterization Challenges of Heterogeneous Network Devices

(Invited paper)

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ABSTRACT

Technological advances in architecture design and semiconductor ICs are well underway to realize small form factor multi-radio systems. Optimizing the functionality and performance of radios in small form factor platforms requires the system architect to give special attention to many aspects of the design. System-level modeling and accurate RF characterization of multiple radios are needed to fully understand the complex RF interactions and to develop a consistent design methodology. RF interference mitigation and noise cancellation techniques for multi-radio platform will have to be devised and incorporated for the proper operation of these heterogeneous wireless systems. This paper will review the challenges in the design and modeling of multi-radio communication systems. RF characterization approaches of mixed network handset will also be discussed. As a case study the impact of platform noise and radio interference on GPS receiver performance, and Bluetooth -WLAN radio co-existence in a small form factor proof concept device will be illustrated.

INTRODUCTION

It is becoming more and more evident that tomorrow's network environment will be extremely heterogeneous. Future communication devices should support key usage models such as simultaneous voice and data transmissions, multi-media applications that scale across networks, seamless handoff, location-based services etc. [1]. Handheld devices that operate under multiple wireless protocols are being developed to demonstrate seamless transfer, interoperability, and radio coexistence of multiple wireless network devices. Such a communication device necessitates high-level integration of digital, analog and RF circuitries within extremely small size. Optimizing the functionality and performance of radios in small form-factor platforms requires the system architect to give special attention to many aspects of the design. These include mechanical form-factor design, tuning of multiple ICs for appropriate radio bandwidths, noise isolation, antenna characteristics, RF interference and spatial proximity.

The characterization of interoperability and co-existence of multiple radios integrated on single platform are very critical for successful implementation in a heterogeneous network. The usage model, wireless system standards and IC integration complexity are important parameters to consider for multi-radio system design. System-level modeling and accurate RF characterization of multiple radios are needed to fully understand the complex RF interactions and to develop a consistent design methodology. RF interferences due to the placement of multiple radiating elements in a small form factor device will have to be thoroughly investigated. Moreover, the convergence of communication and computing devices will exacerbate these problems due to the presence of the high speed digital circuits in close proximity to the high frequency RF circuits. This convergence would require high performance computing capability, now available in laptop, to be made available in future small form factor platform operating in multiple wireless protocols. Wi-Max radio, for example, will have very high date rate transmission capability over a range of frequency bands that overlap other wireless system such as WiFi and UWB. It will also have the capabilities of voice centric systems such as GSM, WCDMA etc. UWB radios have a wide band of operation, must operate at very low transmit power and should avoid interference to and from radios operating under WLAN and Bluetooth protocols. RF interference mitigation and noise cancellation techniques for multi-radio platform will have to be devised and incorporated for the proper operation of these heterogeneous wireless systems. Simulation tools capable of developing deterministic models of communication devices are essential in the development of low cost wireless system.

Multi-Radio Platform

Fig. 1a shows the block diagram of a multi-radio platform designed and characterized to study the important issues related to operation of small form factor devices. Fig. 1b shows the fabricated proof-of-concept (POC) device. The application processor (Intel Bulverde processor) interfaces with the baseband processor (Intel Hermon processor) which in turn is connected to the WCDMA module via an MSL bus. The WLAN module, GPS receiver and Bluetooth module are directly connected to the application processor through standard interfaces.

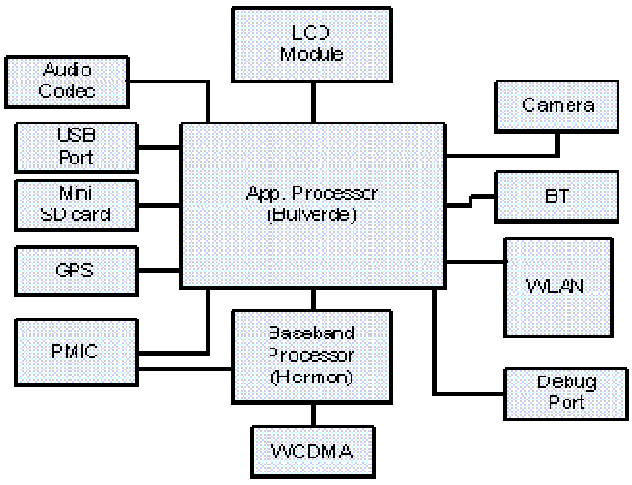
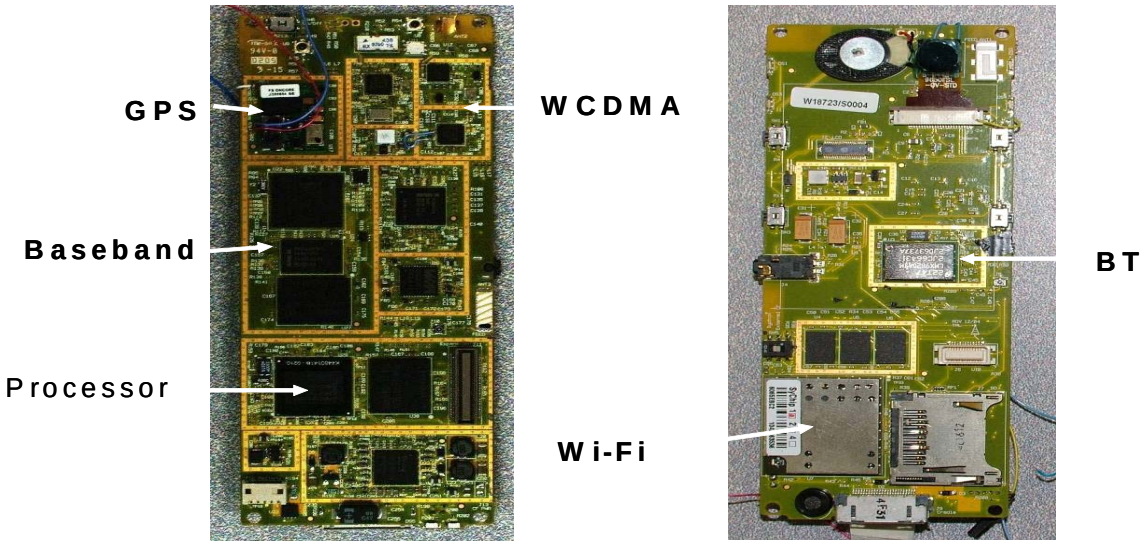


Fig. 1a Multi-radio Platform Architecture

Fig. 1b Proof of Concept Device



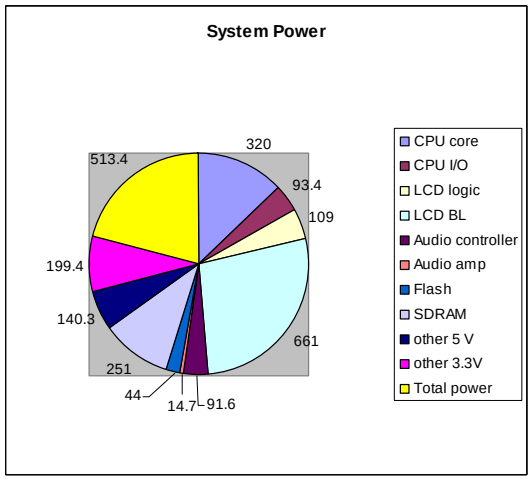
Side 1 **Side 2**

Fig. 2. PCB layout of the POC device showing the location of radio modules

Fig. 2 shows the PCB layout of the multi-radio platform. Radio module and processor chipsets are clearly identified. Special care was taken in the placement of components and radio modules to minimize the noise propagation. Appropriate grounding techniques and shielding was used to minimize the conductive and radiative noises.

Modeling and Characterization Challenges

Modeling and characterization of a highly integrated device like this is rather complex and considerations should be given to several factors. Few of the important steps one should follow in the design of a heterogeneous network platform are: definition of features and requirements, device electrical architecture and implementation, functional validation, power characterization and battery sizing, industrial design, mechanical design and concept validation. System level power management is another critical factor in increasing the battery life time. Fig. 3a shows power consumption of different modules when MPEG4 runs at 400 MHz. Total system power consumption was 2.4 watts. Fig 3b shows the power reduction achievable when the CPU is run at three different states (400 MHz at 1.5V, 200MHz at 1.5V and 200 MHz at 1.25 V) resulting in CPU power saving of 46%. Also, from a platform perspective the system power savings of up to 16% was achieved resulting in prolonged battery life [2]. Some of the power saving approaches that could be incorporated includes processors with voltage and frequency scaling, components with low active and minimal standby power, turning off of power planes as appropriate and development of power policies to optimize overall battery performance.



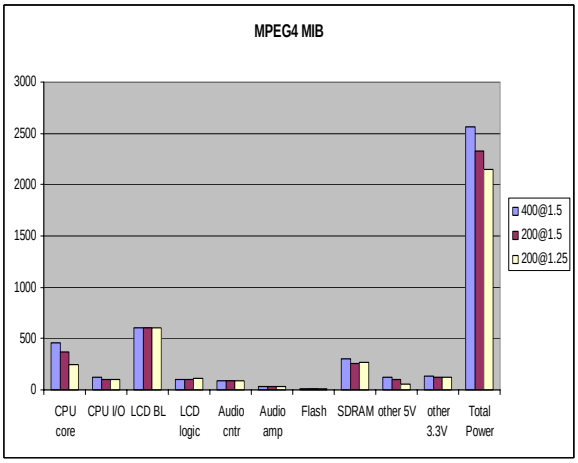


Fig. 3a Power consumption of various platform components **Fig. 3b CPU power control impact**

In a multi-radio platform the noise mitigation and interference minimizations are very critical. Interference tolerances from several concurrently operating radios are to be determined and mitigation techniques have to be developed. Multi-radios in a single platform also require innovation in antenna technology. Innovative antenna concepts like reconfigurable antenna, MIMO antenna have to be developed for small form factor devices. Miniaturized filter technologies employing MEMS switches and bulk acoustic wave technology have to be incorporated for filter miniaturization. Some of the innovative antenna concepts and receiver technologies will be presented in another paper at this symposium [3]. The system level complexity of heterogeneous platform is substantially higher due the increase in functional circuit modules, interfaces, power consumption and high speed data transfer. Methods to handle the increasing complexity of the system include deterministic modeling, standardized interfaces, system level power management, and flexible radio platforms. To achieve the best performance in handheld devices adaptive solutions such as dynamic voltage and frequency scaling and reconfigurable circuits and multi-band antennas have been employed [4].

Multi-radio noise interference can be categorized into three areas: a) platform-to-radio noise, b) radio-to-radio noise, and c) radio-to-platform noise. The sources of noise and mitigation techniques in each of these

categories are different and need to be addressed individually. Platform-to-radio noise sources include the power plane radiation, system clock harmonics, packaging etc. The mitigation techniques include frequency clock shifting, ground and power plane separation, component placement, mechanical case design, RF shielding and software mitigation. The radio-to-radio interference may originate due to the proximity of components, spurious pickup by broadband antennas, transmit power leakage into receive band and isolation. The mitigation technique in this case is comprised of component and antenna placement, RF shielding and new antenna technology. It is also possible to have leakage from RF circuits affecting the other modules in the platform. Placement of the components and the shielding can minimize most of the problem associated with this type of noise.

GPS receiver desensitization exhibited by the POC device is shown in fig. 4a. GPS sensitivity decreased about 3 dB when the Bulverde processor was turned on. When the baseband processor was also turned on, an additional 2 dB of desensitization occurred. The significant deterioration of the GPS receiver sensitivity was observed when WCDMA was turned on. This deterioration is partially due to the physical proximity of the WCDMA to the GPS receiver on the POC device. This graph shows that component placement and proper isolation and shielding are important for small form factor multi-radios.

In fig. 4b the co-existence characterization of Bluetooth and wireless LAN is described. The Bluetooth and WLAN radios were independently tested to confirm that they work with in specification. By interconnecting the radios in different configurations the effect of coupled noise and radioactive noise were independently characterized. When both radios are turned on simultaneously the packet error rate of Bluetooth increased significantly.

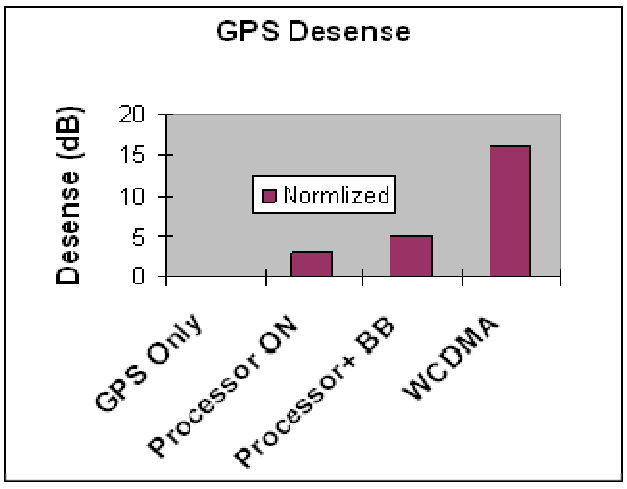


Fig. 4a GPS Desensitization due to Interference

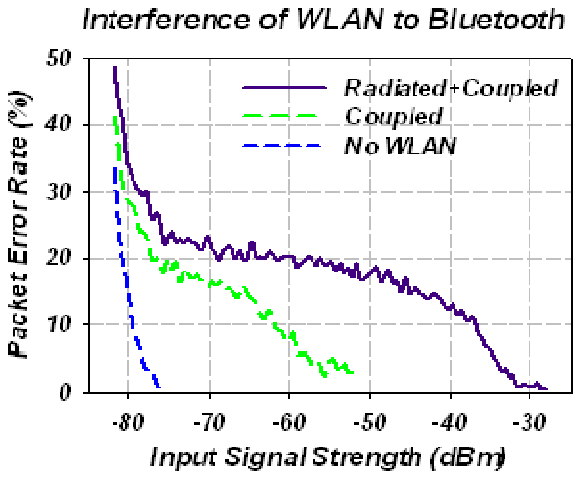


Fig. 4b Bluetooth and WLAN Interference

Acknowledgement

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Reference

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