A Virtual Prototype for Bluetooth over Ultra Wide Band System Level Design

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Abstract

The industry is merging two different Wireless Personal Area Networks (WPAN) technologies: Bluetooth (BT) and WiMedia Ultra Wide Band (UWB), into a single BT over UWB (BToUWB) specification. The goal is to provide low cost, low power and a wide range of data rate wireless communications for multimedia and mobile applications. The complexity to study such a system requires the development of a virtual prototype at a high-level of abstraction. The model needs a fast simulation time in order to explore the algorithms necessary for the merging of the standards. Moreover, as the merging is still in a standardization phase, this virtual prototype helps to actively participate to this effort. The aim of this paper is to provide an overview of the methodology used to create a virtual prototype of a BToUWB device.

1. Introduction

Bluetooth over Ultra Wide Band (BToUWB) is an emerging technology that will bring Bluetooth (BT), the technology leader in the Wireless Personal Area Networks (WPAN) arena, to the high data rate multimedia communications space. As shown in Figure 1, the BT specifications [1] cover the complete protocol stack, from the application layer to the physical (PHY) radio transmission. The WiMedia specifications [2], an Ultra Wide Band (UWB) standard, only define the PHY, Medium Access Control (MAC) and convergence layers. A BToUWB system will then use the BT high level software and profiles, and two different radio paths: the legacy BT radio, which offers low cost and low data rate communications and the UWB path that will provide data rates up to 480 Mb/s.

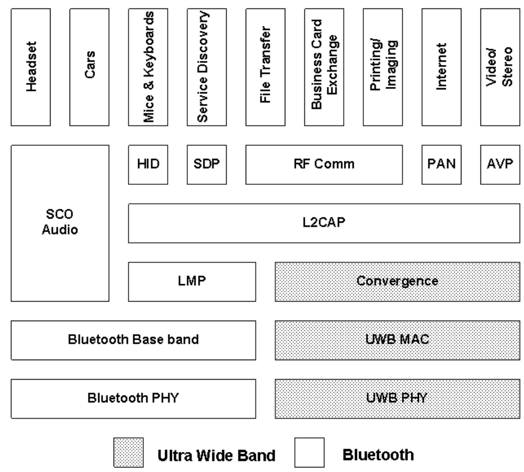

Figure 1 BToUWB Suggested Architecture [3]

Merging these two technologies will allow maximizing and leveraging the benefits of both of them in one single solution. BT is thought to be the more efficient standard in order to keep connection between devices, while WiMedia offers high efficiency for large transfer of data. In order to reach the highest efficiency, a device will integrate high-level algorithms that decide whether to go through the low data rate path (BT legacy radio), or through the high data rate path (WiMedia). To design the algorithms, we chose to develop a model for both standards, which can rapidly simulate the basic functions at a high-level of abstraction. The modeling effort has been done both for WiMedia and BT. The ultimate goal is to have a complete virtual prototype that can help simulating BToUWB communications at the L2CAP level.

The model has been implemented in SystemC [4], which presents the advantages of being able to model both Hardware and Software. Because the specifications of the standards do not define directly the architecture of the systems, the main problem of SystemC development is to identify the different classes and structures that compose

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the model. To do so, we used a co-design methodology that helped us, thanks to a top-down approach, to create a high level view of the system and to define the specifications of the SystemC model.

In this paper, we describe briefly in section 2 the Bluetooth and WiMedia standards. Then in section 3, we introduce the methodology that we used. Section 4 shows the application of the co-design methodology on the WiMedia standard and the structure of the SystemC simulator. We discuss about the future work in section 5 before to conclude.

2. Bluetooth and WiMedia Standards

2.1. The Bluetooth Standard

The BT standard uses a slotted protocol working in the 2.4 GHz unlicensed Industrial, Scientific and Medical (ISM) band. The data rates range goes from 1 Mb/s to 3 Mb/s. BT specifications define all the layers of the OSI protocol stack, from the application layer to the radio layer.

The Bluetooth specification provides two different types of link: Synchronous Connection-Oriented (SCO) and Asynchronous Connection-Less (ACL). A SCO link aims at providing guaranteed delay and bandwidth, and hence is primarily targeting voice links. ACL links are appropriate for non-real-time communication. These links are preferred for data transmission.

2.2. The WiMedia Standard

At the moment, the WiMedia standard defines the MAC and the PHY layers. The Convergence layer, as depicted in Figure 1, is currently being specified in the BT Special Interest Group (SIG). Basically, this layer will be translating the BT commands to the WiMedia MAC commands.

The MAC layer defines a distributed protocol that allows the devices to communicate with their peers through either a Distributed Reservation Protocol (DRP), where devices reserve time slots for packet exchange, or through a contention access protocol called Prioritized Contention Access (PCA).

The PHY layer defines data rates that go from 53.3 Mb/s to 480 Mb/s, depending on the modulation and coding rate used. As shown in Figure 2, the time has been divided into superframes (SF) of 65,536 µs. The SF itself has been divided into 256 Medium Access Slots (MAS) of 256 µs. At the beginning of the SF, all the devices send a beacon during the Beacon Period (BP). The remaining of the SF is considered as the Data Transfer Period (DTP) where data exchange is performed either by PCA or DRP.

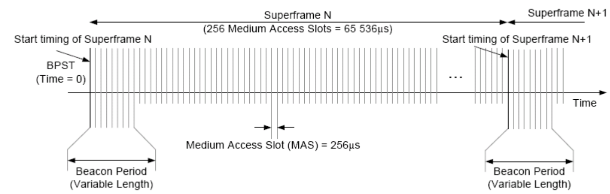

Figure 2 WiMedia MAC Superframe Structure

3. The Co-Design Methodology

To design our system, we use the MCSE methodology presented in [5], also known as Co-Design process. This methodology, based on a top-down design process, consists of a succession of steps that transform an input into an output, which is then passed as input to the next step. In our case, the Requirement definition step is defined by the need of a BToUWB solution. The output of this step is directly the different specifications and standards of such a system.

The System Specification is the step that gives the external view of the system. It defines the system itself in its environment, using formalisms like extended state diagrams. A BToUWB is a Real-Time (RT) system, and therefore, the specifications have to take into account the notion of time, in order to be compliant with the requirements. The output is the Specification document, which is the reference to the design of the functional model.

The representation of the functional model results on the definition of the internal structure of the system, the behavior of the different sub-components and the inputs/outputs and internal data needed to perform all the functions. The functional model is deduced from the specifications and, in turn, will be used as input to the architectural design (which is, for the moment, out of the scope of our study).

Because of the event-oriented protocols and the object-oriented capabilities, the SystemC language is well suited to express the functional solution. SystemC can ease this architectural work because Hardware (HW) can be modeled in SystemC and Software (SW) functions can be implemented in C++. Therefore, the partitioning step between SW and HW can be more efficient with this methodology. In addition, the functional design can be seen as a prototype and experimentation platform used to explore different architectures.

4. The BToUWB Model

4.1. The WiMedia MAC and PHY Model

As we described in section 3, we used the MCSE methodology to define a WiMedia system itself. The requirement document, in this case is described in [2], which gives us all the protocol that needs to be performed at the MAC and PHY levels.

As we described in [7], the functional description of a WiMedia system, after the decomposition of the MAC services and the PHY services can be seen as followed:

First of all, as depicted in Figure 3, peer MAC sub-layers are aimed at exchanging messages “M” according to the WiMedia MAC protocol. They take the instructions from the upper layers (here the convergence layer) by messages “Msg” and reply by the message “Response”.

In order to physically exchange the message M, we need to introduce the Orthogonal Frequency Division Multiplexing (OFDM) service. It is composed by a Transmitter and a Receiver that exchange OFDM symbols (represented by TxS and RxS). This service allows the exchange of messages (M’ and M’’) between peer MAC layers by sampling the data into OFDM symbols. The PHY parameters are shared variables that can be controlled either by the MAC or the PHY layer, represented by TxParameters.

In addition, we implemented the DRP in order to be able to simulate data transfer. The Bluetooth Model

In order to have a complete BToUWB system model, similar work needs to be done for the BT standard. System level implementation of the BT standard, in SystemC, has already been studied in the literature in [8] and [9].

As we can see in Figure 1, the BT defines several layers, from the Radio layer up to the L2CAP layer, which stands for Logical Link Control and Adaptation Layer. The L2CAP is the layer that will need changes in order to incorporate the WiMedia system. Therefore, it was mandatory for us to have a model of the complete protocol stack in order to couple both systems.

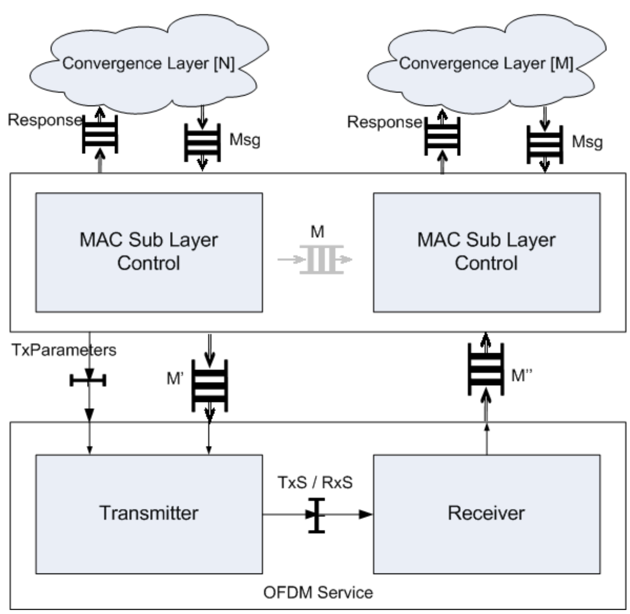

Figure 3 WiMedia System Functional Architecture

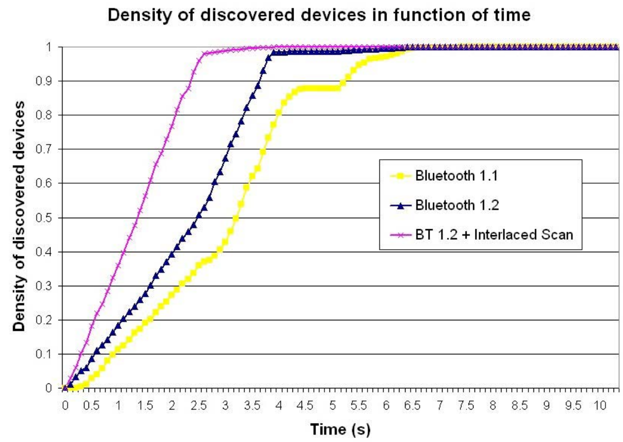

Figure 4 Density of discovered Devices

4.2. The Bluetooth Model

Following the MCSE methodology, we developed an extended model of the Bluetooth standard in SystemC. We kept the architecture of the model as close as possible from functional model in order to have fast simulation time. However this model needed also to be scalable in order to be able to refine some critic blocks, or to incorporate it into a verification environment for co-simulation with HW/SW blocks.

This platform is currently used by the system team in order to develop and verify algorithms that are developed for the future products in NXP. To show the powerfulness of such a model, we present in Figure 4 the results given by the model for comparison of different inquiry procedures performed in different versions of the standard. It represents the density of discovered devices by a master. Using this type of results was used to verify the correctness of our implementation by comparing these numbers to the one given in the standard.

4.3. The BToUWB Model

First of all, one of the requirements for this project was to have the capability to simulate a complete wireless network. Therefore, we needed to introduce a model of the wireless channel. For the moment, the model simply takes as input a packet sent by one of the devices and forwards it to the other devices. It has an algorithm to detect the collisions (simultaneous transmissions) and can also add bit error rate or packet error rate.). As we evolve in a multi-standard environment where standards do not use the same frequency bands, interferences and path loss or multipath will not be modeled for the moment.

The BToUWB model is the result of the implementation in SystemC of the functional models of the BT and WiMedia standards. The convergence layer block is actually the one that requires a lot of attention because it is still under specification and subject of lot of changes. In addition, the L2CAP block is also subject to changes because it has to incorporate new WiMedia / High Speed capabilities that were not define in the actual BT specification.

One of the advantages of this model is that it can perform the whole protocol in a very short simulation time. For example, the simulation of BT connection and then exchange of 1 minute of voice packets takes less than 10s of CPU time on a Linux workstation. For WiMedia, it takes about 2 seconds of CPU time for 20s of a 4 devices network performing only the beaconing algorithm.

5. Future Work

At this point we are able to simulate BToUWB communications and elaborate algorithms that will rule the choice of either the BT legacy radio or the new UWB path. Moreover, as BToUWB is still in a standardization phase, we are able to follow this effort and to test and propose some new procedures.

As BToUWB is the combination of two different standards, the first versions of the end product will surely be a joint architecture of both systems. In order to improve the performances, this platform can help the identification of shared functions. This will lead to the creation of Intellectual Property (IP) blocks that are used to create a dedicated BToUWB architecture.

One of the objectives of this project is also to build a multi-standard platform that will let us experiment coexistence issues between standards. In addition to that, this platform can be extended to any other wireless protocol such as the Wireless Local Area Networks standards (802.11e, 802.11n), in order to have a complete simulator for connectivity protocols. We do not exclude also to extend this platform to the fourth generation of cellular systems.

Another point that can be explored is the emergence of SystemC-AMS [10], an extension of SystemC that is aimed at modeling RF blocks, in order to have a complete virtual platform that include all the protocol stack, from the high layer (application layer) down to the physical layer with a model of the radio. For this step, the advantage of SystemC-AMS is that it is also C++ based and therefore the model will be based on the same language for all the blocks (no co-simulation issues).

6. Conclusions

In this paper, we presented a virtual prototype of a BToUWB system, result of high level modeling activities. The methodology used, the MCSE methodology, helped us to define a high level functional model that will be used as a golden reference for the architectural step. The different classes and objects that are defined in the functional model are the results of a deep study of the standards. SystemC has been used to implement this model because it is really suitable for the implementation of functional models, and is also really convenient to build a virtual platform

As BToUWB is still under specifications, this model will help us to evaluate the performance of the protocol, power and energy per bit consumption in an early development phase ([11]). Moreover, the high level view of the system will allow us to experiment algorithms that will take the maximum of benefits of both standards at the L2CAP level (see Figure 1), which is the common layer of the BToUWB architecture. Moreover, the use of the co-design will help us improving the productivity by reducing the development time with the use of high level models.

Acknowledgements

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