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Zigbee Cross Layer Optimization and Protocol Stack Analysis on Wireless Sensor Network For Video Surveillance

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ABSTRACT- Energy consumption is one of the most crucial design issues in wireless sensor networks since prolonging the network lifetime depends on energy-efficient communication protocols. In order to improve the overall system performance of WSN an optimization technique namely cross layer design can potentially be used by way of jointly optimizing and exploiting the power consumption behavior between various layers of the protocol stack. In this paper, we propose a cross-layer framework design for the ZigBee protocol. In our paper, we describe, analyze, find the research scope and implementation challenges for a reduced ZigBee protocol stack with a specific application, namely the wireless sensor network for video surveillance system. The final goal of this work is to implement an energy efficient ZigBee protocol stack for video surveillance system. An FSM based Zigbee power model will be used for the stack analysis. While implementing, we will also use a cross layer power manager. First, we will implement the energy efficient protocol stack with required functionality, based on the ZigBee specifications. When the protocol stack is completed, we will refine and validate the wireless sensor network for video surveillance system.

KEYWORDS: Wireless Sensor Network, Cross Layer Design, Energy Efficient Protocol, Zigbee.

1. INTRODUCTION

Motivated by the theoretical and practical challenges, wireless sensor networks (WSN) have drawn the attention of the research community in the last few years. This growing interest can be largely attributed to new applications, such as wireless video surveillance systems enabled by new research paradigm. Being a microelectronic device, wireless video sensor node can only be equipped with a limited power source (< 0.5 Ah, 1.2 V) [1]. Therefore, sensor node lifetime becomes strongly dependent on battery lifetime. In an ad-hoc sensor network any malfunctioning of a few nodes can cause significant topological changes and might require re-routing and reorganization of the network. Hence, power conservation and power management becomes challenging issue. For these reasons researchers are currently focusing on the design of power-aware protocols for sensor networks.

The *ZigBee* standard has recently been launched and is targeted specifically towards WSN. The ZigBee protocol is implemented on top of the IEEE 802.15.4 radio communication standard. In particular, the scope of ZigBee is applications with low requirements for data transmission rates and devices with constrained energy sources. The design goals for the WSN have been driven by the need for transmission of small control packet and sensor data and a desire to keep the cost of wireless transceivers to a minimum. Moreover, the network possesses self-organizing capability so that little or no network setup is required [1]. The ZigBee wireless technology enables long battery lifetime and offers the opportunity to build up complex wireless sensor networks.

However, Zigbee protocol stacks, which is architected and implemented in a layered manner, might not function efficiently in mobile wireless environments. In the last few years, a new design paradigm has arisen in the field of wireless sensor network research: the so-called cross-layer optimization. Cross-layer feedback in the protocol stack would be useful to improve the efficiency of this protocol stacks. In fact, this paradigm implies the redefinition of the overall design strategies for this kind of systems as it breaks the classical model. The aforementioned research related to cross layer analysis on WSN aims for particular layer dependent analysis. None of these ever analyze the overall energy efficient system performance due to lack of proper model. Numbers of literature on cross layer analysis between adjacent OSI/IEEE802.11 layers for WSN protocol is available. But research on Zigbee cross layer protocol analysis for WSN is yet to be reported. Thus this wide promising technology for WSN is looming to be unwrapping on full scale. The amount of literature about this issue is still relatively scarce, but the premier published results show that the potential obtainable gains are worthy to deserve the increasingly attention that Zigbee cross-layer is getting. Since the ZigBee 1.0 specification ratified on December 14, 2004 and the latest posted in December 2006 no power consumption model has been presented yet [2]. To implement an energy efficient Zigbee protocol this model would provide remunerative research scope. The rest of the paper is organized as follows: Section 2 provides background and objectives, section 3 states the state-of-the-art. Section 4 presents the proposal with detail research directions and objectives. The end section gives the current results.

2. BACKGROUND AND OBJECTIVES

In this section a brief overview of Zigbee and cross layer optimization with our motivation and Zigbee Cross layer optimization goals for our research is stated.

2.1 Zigbee Overview

ZigBee is best described by referring to the 7-layer OSI model for layered communication systems. The ZigBee specification is managed by a non-profit industry consortium of semiconductor manufacturers, technology providers and other companies, all together designated the ZigBee Alliance. The ZigBee specification is designed to utilize the features supported by IEEE 802.15.4 [2]. A comparison of prevalent wireless technologies is presented in Table 1.

	Zigbee	Bluetooth	Wi-Fi
Standard	802.15.4	802.15.1	802.11b
Memory requirements	4-32KB	250KB+	1MB+
Battery life	Years	Days	Hours
Node per master	65,000+	7	32
Data Rate	250Kb/s	1Mb/s	11Mb/s
Range	300m	10m	100m

Table 1: Comparison of wireless technologies

ZigBee is poised to become the global control/sensor network standard. It has been designed to provide the following features:

- Low power consumption.
- Low cost (device, installation, maintenance).
- High density of nodes per network.
- Simple protocol, global implementation.

The IEEE 802.15.4 PHY adopted by ZigBee has been designed for the 868 MHz band in Europe, the 915 MHz band in N America, Australia, etc; and the 2.4 GHz band is now recognized to be a global band accepted in almost all countries.

A ZigBee system consists of several components. The most basic is the device. A device can be a full-function device (FFD) or reduced-function device (RFD). A network shall include at least one FFD, operating as the personal area network (PAN) coordinator. An RFD is intended for applications that are extremely simple and do not need to send large amounts of data. The FFD can operate in three modes: (PAN) coordinator, a coordinator or a device. An FFD can talk to RFDs or FFDs while an RFD can only talk to an FFD. ZigBee functional layer architecture in ZigBee is shown in Fig 1.

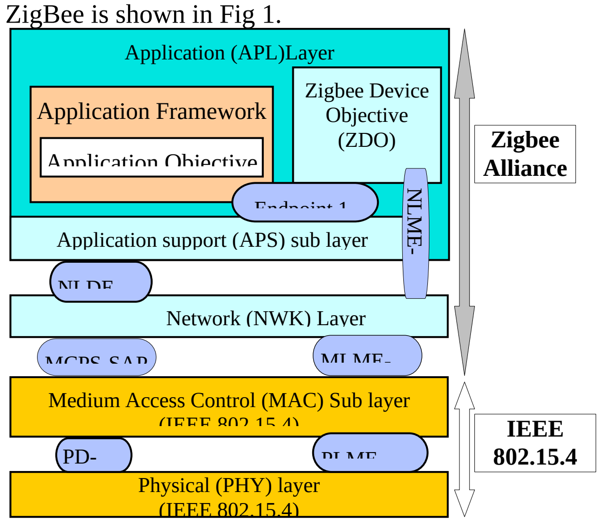

Fig.1. ZigBee functional layer architecture and protocol stack.

2.2 Cross Layer Optimization

In general, cross-layer design and optimization means that the different layers are allowed to couple, integrate, and exchange information between one another, to a much higher degree than what was originally intended when the classical layers of the protocol stack architecture was designed [9].

Cross-layer research Motivations: Several reasons have motivated the Zigbee cross-layer optimization research for the wireless sensor networks:

- **Optimization in one layer may need to interact with other layers to show its effects:** Due to having a possibility of confrontation on different approaches for the same optimization goal, cross layer optimization seems to be the solution. For example, designing an energy efficient WSN protocol we need an energy efficient routing. Let's assume that a proposed routing protocol will always select among the shortest routes so that they will pass through the most densely deployed area. Compared with a single larger-distance hop the advantage of this kind of routes is that for the same transmission distance, taking more number of smaller-distance hops, it can save transmission power. However, a severe contention might occur due to data transmission with more hops. If proper care is not taken on MAC layer design optimization, the advantages of the routing design may be counteracted by the increasing power

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consumption due to the increase of contention possibility [18].

- **Conflicts avoidance between optimization goals:** Some solutions for aforementioned optimization goals might conflict with each other. This leads to a consolidate design the most promising solution for actual applications. The effort pretends to fit every optimization into a complete application package and thus achieve all possible optimization goals in an integrated way.
- **Removal of unnecessary layer support:** Some situations do not need supports by all layers. In that case, the most efficient way of optimizing the system is to remove those unnecessary layers. It is advisable that the composition of the protocol stack to support certain applications can also be optimized by the cross-layer approach.

2.3 Zigbee Cross layer Optimization Goal

Followings are the three goals of this Zigbee cross layer protocol analysis

- The Major goal of this research is to develop an FSM based power consumption model (characterization, measurement, ect) to improve the power efficiency of the Zigbee protocol stack.
- Another goal of this Zigbee cross layer optimization and protocol analysis is energy constrained cross-layer protocol design and optimization. Sensor nodes can only transmit a finite number of bits until they run out of energy. Consequently, reducing the energy consumption per bit for end-to-end transmissions is an important design objective for such networks. Since all layers of the protocol stack affect the energy consumption per bit for data transmission from source to destination, energy minimization requires a joint design across all layers [10].
- Another goal of this research is to provide a feasible and flexible mechanism to solve the conflicts between the requirements of long lifetime and the constraints of limited node resources, small bandwidth and low battery capacity [11].

3. CROSS-LAYER OPTIMIZATION AND ZIGBEE: RESEARCH DIRECTIONS AND STATE-OF-THE-ART

Cross-layer optimization in WSN has been addressed by multiple studies in different scenarios. The basic idea is to design communication layers such that they can share and react to layer-specific information at different layers in the communication stack. In recent years, researches are using cross-layer design for high efficiency and low cost WSN communication systems. These efforts can be roughly classified into four categories according to their optimization goals.

Energy-Efficiency [12][13]. Cui *et al* [13] show that joint design optimization across hardware, link layer, MAC, and routing is a beneficial and feasible approach to implement an efficient energy-constrained wireless network. The authors also investigate joint estimation problems in an energy constrained sensor network where they consider the source coding and the channel coding jointly. Cross-layer design based on computation of optimal power control, link schedule, and routing flow is described in [14]. The aim of that paper is to minimize the average transmission power over an infinite horizon.

Quality-of-Service (e.g. throughput, delay and data loss). Energy efficient power control and scheduling, with no rate adaptation on links, for QoS provisioning are considered in [15]. In [16] utility functions are constructed from measurements of the different OSI layers to provide input into their cross-layer optimization engine. ZigBee technology was chosen as the test platform to demonstrate their proposed mechanism. The research describes a mechanism to improve communication performance and efficiency in a specific wireless network environment. An application is designed to adapt to different situations, denoted by the environment, and by achieving certain behaviors. Authors propose to have one Cross-Layer Optimization Engine (CLOE), the software, to reside in each wireless node. It performs cross-layer optimization using measurements from different layers. Each CLOE formulates an optimal decision based on various parameters. CLOE is antenna, radio and channel configuration agnostic.

Robustness (e.g. node failure, transmission errors). Chiara Buratti et al. propose [17] a new energy-efficient scheme for data transmission in a wireless sensor network (WSN), having in mind a typical application including a sink, which periodically triggers the WSN, and nodes uniformly distributed over a specified area. Routing, multiple access control (MAC), physical, energy, and propagation aspects are jointly taken into account through simulation. Zhaug et al [18] study the application oriented cross-layer protocol design and optimization. The goal of the study is to provide a feasible and flexible approach to solve the conflicts between the requirements of large scale, long lifetime, and multi-purpose wireless sensor networks and the constraints of small bandwidth, low battery capacity, and limited node resources. Varun et al [19] present a cross layer methodology for the analysis of error control schemes in WSN such that the effects of multi-hop routing and the broadcast nature of the wireless channel are investigated. That analysis enables a comprehensive comparison of forward error

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correction (FEC) and automatic repeat request (ARQ) in WSN.

***Resources Allocation*.** Based on the 802.15.4 technology [20] presents a software architecture where cross-layer management entity and low levels of the protocol stack has been combined. The architecture is aimed for wireless sensor network nodes with reduced resources. The main idea is to implement the wireless sensor network's basic tasks, such as topology management and power saving functionalities, as separate protocols in cross-layer management entity. Data structures, which are in common use, are also implemented in cross-layer management entity. Shah et al. [21] present protocols for routing, MAC and power-control and jointly optimize these protocols. Authors modeled the protocol stack as a whole, rather than a collection of individually modeled layers. They combine the routing, MAC and power-control protocols to obtain the constrained optimization problem. Though authors mention this analysis as joint optimization of protocol stack, here they emphasize the particular rendezvous MAC scheme layer protocol called TICER (Transmitter Initiated CyclEd Receiver). The goal of [22] is to make a comprehensive literature review of sound cross-layer protocols, protocol improvements, and design methodologies based on the joint solutions of resource allocation optimization problems at different layers. Lubrin et al. [23] have recently reported a wireless remote healthcare monitoring that takes advantage of he ZigBee wireless link. This system is based on the Berkeley Motes platform and each node could be used to monitor body temperature, heart rate, as well as many other parameters. However this work is focused on a set of wearable sensors and does not directly address implantable solutions. Table 2 shows a summery of a few ongoing projects on cross-layer design of WSN.

Project Name	Research Area
NORDITE	Cross-layer optimization in short-range WSN (CROPS)
e-SENSE	Reconfigurable protocol solutions (Energy efficient air interfaces for WSNs)
TinyCubus	Cross-layer framework for WSNs.
EMMA	Cross-layer framework design using optimization agent
ZebraNet	Middleware system (Impala) uses cross-layer data.

Table 2. WSN projects on cross-layer design

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