Comparing ZigBee, Bluetooth, UWB, and Wi-Fi

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INTRODUCTION

In this article, we compare four distinct protocols for different wireless communication solutions. ZigBee, Bluetooth, and Ultra Wideband (UWB) represent some of IEEE standards for wireless personal area network (WPAN). WPAN applications transmit information over a short distance between a group of devices and are usually self contained with little or no need of connecting directly with devices outside the group. Wi-Fi is a wireless local area network (WLAN) standard. WLAN applications need to connect with external devices outside the group.

Our goal is to provide a better understanding of these emergent technologies, highlighting their characteristics and the critical issues of their protocol designs. All four wireless technologies presented here have their physical layer (PHY) and medium access control layer (MAC) defined as an IEEE standard. This article is organized as follows: the first section introduces each one of these protocols. A comparison of these protocols is presented in the second section, mainly focusing on transmission range, operating frequency, data rate, modulation scheme, interference and coexistence mechanisms, network size, security, authentication, and QoS. Lastly, the article is concluded with some final remarks.

WIRELESS COMMUNICATION PROTOCOLS

In this section, we describe the main characteristics of each one of these four protocols, outlining their architecture and network topology.

ZigBee Technology

The mission of ZigBee alliance (ZigBee, 2005) is to provide reliable, cost-effective, low power, monitoring and control products wirelessly networked based on an open global standard. ZigBee protocol is targeted for home security, access control, energy management, lighting control, mouse, keyboard, and wireless sensor networks.

The ZigBee network style began to be conceived in 1998 when several engineers realized that either Bluetooth or Wi-fi were unsuitable for applications that needed self-organizing ad-hoc digital radio networks. In December 2000, IEEE 802.15.4 started its project for WPANs, and the standard was released in May 2003. In June 2005, the ZigBee specification version 1.0 was announced. Future radio physical layers for WPAN will likely use UWB technology for improving ZigBee throughput (Ellis, 2004).

The IEEE 802.15.4 standard (IEEE, 2003a) defines the medium access control layer (MAC) and physical layer (PHY) of the ZigBee stack architecture. The ZigBee alliance platform specifies the upper layers such as the network (NWK) layer and the framework for the application layer ZigBee stack. Protocol code size is expected to be smaller (Kinney, 2003) when compared with other wireless protocols, allowing these devices to be simpler and with less memory needs.

The PHY is intended to provide low cost devices yet provide high levels of integration. The use of direct sequence spread spectrum (DSSS) modulation technique allows simpler circuit implementation, and thus the implementation of low cost devices.

The MAC layer is intended to enable the implementation of multiple topologies with low complexity. It supports reduced function devices (RFD). However, RFD is intended for applications that are extremely simple. Because they do not have the need to send large amounts of information, they do not need large memory (RAM or ROM) capabilities.

The NWK layer was designed to enable network growth with no need of devices with more transmission power. The NWK supports extremely large networks with many nodes, with low latency, and high reliability.

Figure 1. ZigBee topology models
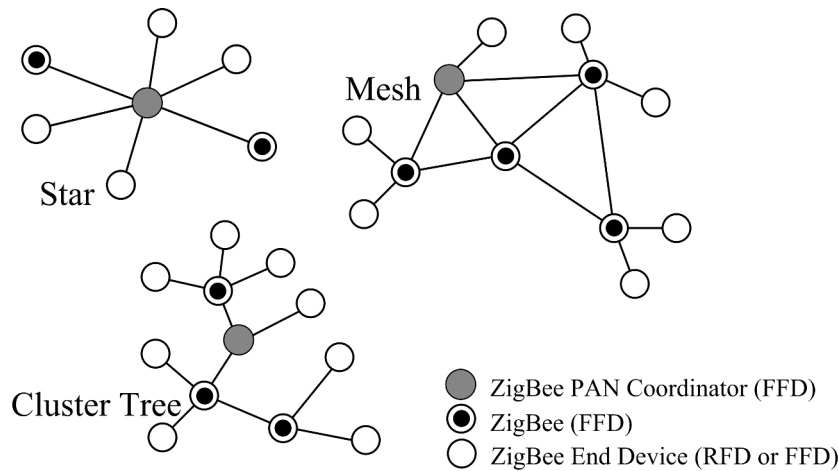
Moreover, NWK supports several network topologies: *star*, *mesh,* and *cluster tree* (Figure 1). In star topology, communication is established by only one PAN (personal area network) coordinator. The coordination functions are more energy consuming while other devices will most likely be battery powered. These devices spend 99% of their lifetime in sleep mode saving battery power. The *mesh* topology has a PAN coordinator, which differs from *star* topology because any device can communicate with each other as long they keep in range. Applications such as industrial control or habitat monitoring benefit from this network topology. The *cluster tree* topology is a special case of a peer-to-peer network. In this topology, devices communicate using a hierarchical routing strategy. If the destination is a descendant of the device, then the frame is routed to the appropriated child device. If the destination is not a descendant device then the frame is routed to its parent. In this case, most of the devices are full-function devices (FFDs). RFD devices may connect as a leaf node at the end of a branch. Any FFD can act as a coordinator providing synchronization services, although there can be only one PAN coordinator per network.

Bluetooth

Bluetooth (Bluetooth SIG, 2003) wireless communication technology is based on radio frequency (RF) system for short range. Bluetooth not only offers support for radio interface, but also for a whole set of communication standards that allow devices to find others and publish offered services. The main purpose of Bluetooth is the cable replacement for connecting devices such as PC communicating to printers, fax machines, mouse, keyboard, etc.

The Bluetooth special interest group (SIG) was formed in 1998. In 1999, the Bluetooth version 1.0 specification is released. The IEEE 802.15.1 standard (IEEE, 2002) defines the wireless MAC and PHY specifications for WPANs and is based upon technology originally developed by the Bluetooth SIG. The current Bluetooth specification version 2.0 was released in 2004, and introduces enhancements in data rate. Current status shows that Bluetooth SIG plans to adopt Ultra-wideband radio technology (Ferro & Potorti, 2005), enabling very fast data transfers.

The Bluetooth protocol stack is specified as several separated layers. We describe briefly the layers involved in MAC procedures. The *baseband layer* specifies the lower operations such as forward error correction (FEC) operations, encryption, cycle redundancy check (CRC) calculations to detect errors and automatic repeat request (ARQ) protocol, and retransmit a sent packet automatically when needed.

The *link manager layer* specifies the connection establishment and release, authentication, QoS, power management tasks, and traffic scheduling.

The *logical link control adaptation protocol (L2CAP) Layer* manages connection-oriented and connectionless services to upper levels. It handles the multiplexing of higher layers protocols, the segmentation, and reassembly (SAR) of large packets.

In this protocol, we can identify two major connectivity topologies (Figure 2): the *piconet,* which is formed by one master device and up to seven active

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