Comparative Assessment of Protocols used for Low-Power Mechanisms in WSNs

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Abstract

This paper provides a comparative assessment of the IEEE 802.15.4/ZigBee protocol and 6LoWPAN protocol. The main focus of this paper is to check the impact on performance of network due to the low power mechanisms of these protocols. For a fair comparison of performance the protocols are compared under same network conditions. This assessment trys to bring out the weaknesses and strengths when low power mechanism is used for both the protocols.

Keywords: WSN, IEEE 802.15.4/ZigBee, 6LoWPAN

Introduction

The use of protocols 6LoWPAN and IEEE 802.15.4 is widespread in factory automation for monitoring functions such as assessing machines for preventing failures or measuring consumption of plant energy. This paper performs comparative assessment of the low-power operating mechanism of 6LoWPAN and IEEE 802.15.4 for commercial WSNs. The low-power modes in these protocols work by putting nodes to sleep and thus their duty cycle is decreased. The comparative assessment can be performed by making them work in the same network conditions. Hence first the operating parameters of the two protocols need to be tuned for achieving this. The operating parameters of the two protocols are quiet different hence the tuning is not direct. Even though both these protocols use the IEEE 802.15.4 PHY and MAC, still they use different methods for saving energy and multi-hop communication. The protocol IEEE 802.15.4 uses the beacon enabled mode which will allow the nodes to be usually in low power sleep state. For achieving Multi-hop transmission with sleeping nodes the tree routing protocol through the cluster-tree hierarchy can be used [1]. The 6LoWPAN protocol uses IPv6 and is based on a mesh topology which uses a routing algorithm that does not take care of sleeping nodes. It requires approaches such as low-power listening [2] for saving energy.

Related work

Various studies for performance analysis of the protocol IEEE 802.15.4/Zig-Bee is present in the literature. These performance studies make use of experimental measurements, analytical models as well as simulations. Performance analysis of slotted IEEE 802.15.4 in a star network topology is given in [3], that takes into consideration both saturated and unsaturated periodic traffic scenarios. The performance assessment of low-power IEEE 802.15.4/ZigBee networks is done using simulation and analytical model in [4]. Star and tree ZigBee network is analyzed in [5] by using hardware and software available in market with the goal of finding the weaknesses and strengths of the technology. But all these studies give only some parametric analysis and does not provide comparison with other protocols. This paper provides performance comparison of low-power operating mechanism in 6LoWPAN and IEEE 802.15.4/ZigBee protocols.

Due to the several opportunities given by the combination of WSN and Internet technologies the 6LoWPAN protocol is getting attention of the market as well as research. In [6], the choices made in the design of the 6LoWPAN protocol and the difficulties and challenges for future development are discussed. To take advantage of WSN integration [7] provides a method for using 6LoWPAN protocol with IPv4 networks. To enable real time transmissions with 6LoWPAN the SPEED geographic routing algorithm in a 6LoWPAN environment is given and its validation in a real test bed using experiments is discussed in [8]. In [9] experimental measurements are given for evaluating protocols. However assessment of other WSN technologies is not given. In [10] a comparative assessment of capabilities given by some rival technologies for home automation is specified. A comparative evaluation is given between protocols operating in low-power mode for WSN in [11], where comparison of 6LoWPAN is given with the Collection Tree Protocol and Multi-hop Link Quality Indicator Protocol. However ZigBee which is currently widely used protocol in WSN is not taken into consideration. This paper provides performance analysis of 6LoWPAN protocol and IEEE 802.15.4/ZigBee when low-power mechanisms are used. In sensor nodes power consumption for transmission, reception and idle states are similar while during sleep state power consumption is comparatively smaller.

IEEE 802.15.4/ZigBee

The IEEE 802.15.4 standard [12] defines the physical and MAC layer of low-power Wireless Personal Area Net-work (WPAN). This is a protocol which is used for low-rate and low-power communications, particularly suitable for small embedded devices such as sensor nodes. This protocol allows for varying nodes' duty cycles from 100% to a minimum of about 0.1%.

The IEEE 802.15.4 MAC protocol has two modes of operation. First is a non-beacon enabled mode in which a classical unslotted CSMA/CA mechanism is used by nodes for accessing the channel. Second is a beacon enabled mode which uses a slotted CSMA/CA method that incorporates duty cycling to conserve nodes energy. This mode uses a super frame structure which is flanked by beacon frames sent by a coordinator for synchronizing the associated nodes.

The super frame structure shown in Fig. 1 is divided into two parts: an active and inactive part.

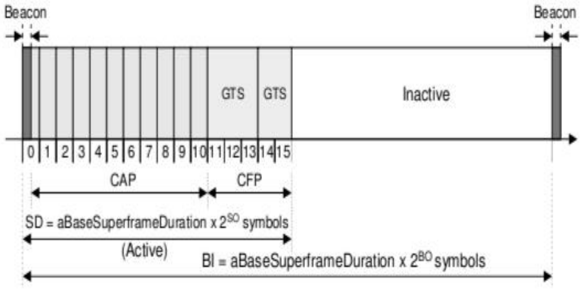

Figure 1: IEEE 802.15.4 Superframe [12]

The active part of super frame is partitioned into 16 slots having equal duration. Nodes can access the channel to transmit their data at the boundary. The active part is further partitioned into two subparts: the Contention Access Period (CAP) and the Contention Free Period (CFP). In CAP medium access is regulated by slotted CSMA/CA, and in CFP, to access channel without contention, up to seven Guaranteed Time Slots (GTS) can be given. During the inactive part nodes can save power by turning their radios off as there is no communication. As nodes will be sleeping during the inactive period of the super frame, the duty cycle (DC) of nodes only relies on super frame structure. When IEEE 802.15.4 nodes use their low-power mechanism in the beacon enabled mode, for achieving communication between coordinator and its devices two different mechanisms for data transfer are used, direct mode and indirect mode. During direct transfer the device must wait for the beacon frame that is sent by the coordinator for synchronizing with the super frame next packet can be sent from the device to the coordinator. The data is then send in one of the super frame slots, next when coordinator receives the packet it sends an acknowledgment for completing the transmission. The indirect data transfer mode is used when coordinator has pending data for its devices. The coordinator will indicate in the beacon frame that it wants to send data for the device. Next the device on receiving the beacon frame must send a data requisition frame. The coordinator will then send acknowledgment for the received data request frame followed by the data packet. Finally for completion of transmission the network device sends an acknowledgment. The duty cycle for deterministic nodes depends only on the super frame parameters. Hence ZigBee networks by using beacon enabled mechanism permit for deterministic nodes duty cycles. For meeting energy consumption requirements of the network these parameters can be set at the time of design. However due to overhead of indirect communication and increased complexity the performance of real time data transmissions is affected. Also the time required to wait for the next active super frame affects the throughput of real time data transmissions.

6LoWPAN

The 6LoWPAN protocol makes it possible for the smallest devices that have low processing ability to send information wirelessly using Internet Protocol. The 6LoWPAN protocol specification [14] allows IPv6 communications over limited power wireless network devices. The RFC specifications define IP-based WPANs' network layer which uses the IEEE 802.15.4 physical and medium access layers. For small devices such as wireless sensor nodes and embedded devices IPv6 standard is too cumbersome. This was the main motivation behind developing 6LoWPAN. The standard IP protocol is not suitable for Wireless sensor networks due to various reasons. For example the data from sensor that is sent over a Wireless Sensor Network is smaller as compared to the standard IPv6 header which is 40 octets. The TCP or UDP protocol adds another 20 and 8 octets respectively which is an additional overhead. MAC layer provides maximum frame size of 102 octets so less number of bytes will be present for data transmissions. Also some fragmentation is needed as the maximum transfer unit of IPv6 which is 1280 octets is bigger than the maximum frame of IEEE 802.15.4. Routing mechanism and addressing problems exist due to the support of IP over IEEE 802.15.4 MAC and PHY. The problem is that IP-based networks' routing protocols cannot deal with sleeping nodes. Also IEEE 802.15.4 and IP make use of different addressing formats. 6LoWPAN introduces an adaptation layer between the network layer and the MAC layer. This layer helps in shortening the header to a few bytes. It also retains the important functionalities of IPv6. The 6LoWPAN adaptation layer provides interoperability with IP networks. This layer supports fragmentation and reassembly. It supports address mapping between IPv6 and IEEE 802.15.4 addresses.

The 6LoWPAN specification relies on lower layer approaches and does not have any specific method for achieving communication using low-power. For achieving energy efficiency in 6LoWPAN networks the IEEE 802.15.4 protocol's low-power capabilities must be exploited. In 6LoWPAN beacons enable discovery and association of devices.

6LoWPAN provides the impression to the upper layers that the receiver is always on even though it is actually off most of the time. 6LoWPAN utilizes Low Power Listening (LPL) [2] technique for allowing distributed and asynchronous access to the channel by the nodes.

The working of Low Power Listening (LPL) [2] technique is as follows: An idle node wakes up at regular intervals and checks for activity after turning the radio on. The node switches off the receiver and goes to sleep if activity is not sensed. If activity is sensed, the node stays awake till the reception of the packet. During a false positive until timer expires the node remains awake. Working of LPL operations is as given in Figure 2 [2]. The false positives reduce energy-efficiency of the protocol hence an accurate channel assessment is very important. This method is incorporated to work in noisy environments [15] as well.

The preamble of packet should be as long as interval in between two subsequent LPL samples so as to evade packet losses while the node is in sleep mode.

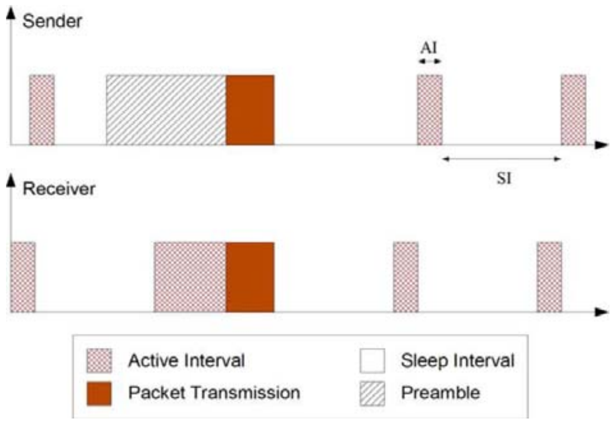

Figure 2: Low Power Listening [2]

Conclusion

This paper compares performance of 6LoWPAN and IEEE 802.15.4 protocols for industrial use of Wireless sensor networks. A qualitative evaluation of the low-power features of the two protocols is addressed. This can be the basis for tuning the low-power relevant configuration parameters ie., the BO and SO for 802.15.4/ZigBee and the AI and SI for 6LowPAN for getting preferred duty cycle in a realistic test bed. From these evaluations useful suggestions for the network designer are obtained that permit him to choose the technology that is most suitable for the required performance objectives like a given duty cycle, a given maximum delay or packet loss. The IEEE 802.15.4 protocol permits a network designer to carry out energy planning by fixing the duty cycle for nodes. The tuning should be done meticulously due to overlapping issue of super frame. 6LoWPAN protocol however does not need to synchronize nodes. But the overall network load decides the node's duty cycle hence it is more complicated to decide the duty cycle and therefore the energy consumption.

Future work will provide a broader comparison with more diverse sets of parameters for both 6LoWPAN and IEEE 802.15.4 protocols and diverse network topologies.

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