Adaptive Channel Selection Algorithm for a Large Scale Street Lighting Control ZigBee Network

A. Lavric¹, V. Popa¹, S. Sfichi¹
¹Department of Computers, Electronics and Automation, Stefan cel Mare University, Universității St. 13, RO–720229 Suceava, Romania
lavric@eed.usv.ro

Abstract—The present paper introduces an adaptive channel selection algorithm that can be integrated in a ZigBee network performing in an environment that is highly affected by IEEE 802.11 interferences. The algorithm can be implemented when a tree network topology is used. The interferences are detected by means of an ACK/NACK type algorithm. When interference is detected, each node of the network contributes to the selection of the optimum channel performance. A series of tests have been conducted in order to validate the performance of the suggested algorithm. Even when the RF environment is congested, the coordinator is able to make the optimum selection of the operating channel for the entire network.

Index Terms—IEEE 802.15.4, channel selection algorithm, street lighting control, ZigBee.

I. INTRODUCTION

Wireless networks are becoming more widespread, thus causing the congestion of the radio frequency environment. The scientific literature includes a series of papers that approach the allocation of the optimum performance channel within an IEEE 802.15.4 ZigBee sensor network that operates in an environment that is highly affected by interferences – mostly of the IEEE 802.11 type [1]-[9].

None of these papers approaches the issue of determining the optimal operating channel that can be applied in a street lighting monitoring and control system.

In the implementation of a lighting control system by employing the IEEE 802.15.4 standard which also includes the ZigBee communication protocol, each lamp is integrated in a network and thus becomes a node [10]. As presented in a related paper [11], the tree type network topology ensures a high performance level in terms of end-to-end application delay, throughput, number of hops and the possibility to integrate a large number of nodes. Thus, the tree topology is recommended when a monitoring and control street lighting system is implemented. This system is of the long-thin type and it can incorporate more than a few hundred nodes [11].

The aim of this paper is to propose a novel adaptive channel selection algorithm that can be integrated in a street lighting control architecture operating in an environment that is highly affected by interferences. The algorithm can be used when employing a tree network topology.

II. CHANNEL ALLOCATION

This section presents, an analysis of the channel allocation for the IEEE 802.11 standard and IEEE 802.15.4. The communication channels provided in the 802.11g standard have a bandwidth of 20MHz, as shown in Fig. 1.

![Fig. 1. Channel overlapping IEEE 802.1 and IEEE 802.15.4.](http://dx.doi.org/10.5755/j01.eee.19.9.5659)

The bandwidth of an IEEE 802.15.4 channel is about 2 MHz, just as the frequency guard interval and therefore the channels that do not overlap are very few (for example channels 1, 5, 9 and 13 for IEEE 802.11g EU zone). As shown in Fig. 1, the selection of the optimal channel for the IEEE 802.15.4 network when the RF environment is congested is still a highly debated issue [12].

III. ADAPTIVE CHANNEL SELECTION ALGORITHM

The coexistence of the IEEE 802.15.4 and the IEEE 802.11 networks, as well as the channel allocation, can be addressed by assessing the interferences from an AP (Access Point) IEEE 802.11 to an IEEE 802.15.4 network [13]. Thus, an algorithm is suggested for the adaptive channel selection in an environment that is highly disturbed by interferences. In [14] is presented an adaption system for interferences in order to obtain a high level of performance in an IEEE 802.15.4 network that uses a mesh topology. The disadvantages of the suggested algorithm are that it assumes...
that after the occurrence of interference (IEEE 802.11) the nodes can still communicate which represents an optimistic scenario [15]. In [16], is presented an adaptive channel allocation algorithm, by means of interference detection and based on a random adaptive channel selection scheme. This channel selection method can be implemented when the RF environment is congested and it is difficult to determine the free channel. In the case of an IEEE 802.15.4 network, the operating channel is selected by the coordinator node. In the case of a large scale network that consists of several hundred nodes spread across a large geographical area, it is preferable that each node should contribute to the channel selection in order to ensure as high a level of performance as possible.

The present paper focuses on designing and testing an adaptive channel selection (ACS) algorithm that can be integrated in a street lighting monitoring and control system spread across a wide a geographical area of several kilometres, which operates within an environment that is highly disrupted by interferences. The ACS scheme entails that each device in the network should contribute to the optimal selection of the operating channel. Since the network can consist of a large number of nodes, it can be affected by a number of 802.11 access points, leading to a significant decrease in the performance level and thus compromising the entire system. Thus, when a WLAN interference is detected, the ACS algorithm determines the optimal operation channel. The algorithm consists of two stages: the interference detection and the procedure to avoid them. The first part of the algorithm entails the detection of interferences. The second part is the avoidance of interferences by determining the communication channel as shown in Fig. 2.

The node that initializes the ACS algorithm is the coordinator. When a node detects the occurrence of interference, it sends an ACS request to the coordinator node. The coordinator, depending on the number of nodes that send ACS requests, decides when the entire network enters the ACS scanning mode. There are basically two ways to prevent interferences: the global or the local allocation of the communication channel. The global channel allocation in a wireless sensor network assumes that all nodes use the same channel. The disadvantage of this method, as a result of the spatial identification of the local Wi-Fi interferences, consists in a possible decrease in performance in certain network areas. Also, as interferences multiply, it is almost impossible to select a free channel [17]. If a local channel allocation method is used, various nodes or the same node at different time intervals can communicate on different channels and thus prevent interferences. The suggested ACS algorithm uses a global channel selection method.

However, two main problems remain: the methods used for the assessment of the interference intensity and for the assignment of the channels so that each node can communicate accordingly. In the case of severe Wi-Fi interferences, the node must select a new channel in order to avoid the drastic decrease of the performance level. This operation is conditioned by the moment and the assessment of the interference intensity.

The efficient detection of interferences in IEEE 802.15.4 networks is an important issue. The interference detection algorithm is based on the ACK/NACK (Acknowledgement) mechanism. Since this system does not require any redundant procedures for detecting interferences, it can be seen as a good candidate that can be used in a large-scale, long-thin street lighting monitoring network. When a node sends a message, the ACK confirmation message is expected from the recipient node. When the ACK message is not received after a certain time, the NACK counter is reported and incremented, and when the ACK is received, the counter is reset to zero. Thus, when the NACK reaches the maximum number of consecutive retries and, implicitly, a maximum threshold value, the source node decides it is being affected by interferences, as shown in Fig. 3. The threshold value can be selected when the network is implemented.

Fig. 2. Simplified flowchart of the adaptive channel selection algorithm.

Fig. 3. ACK/NACK algorithm.

Fig. 4 shows the logical diagram of the proposed ACS

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**Fig. 2**: Communicate on the selected Channel → Monitor Interferences → Interferences Detected? → Send ACS Request to Coordinator

**Fig. 3**: START → ACK Received? (Yes) → NACK++ → NACK=0 (No) → Another NACK? (Yes) → INTERFERENCE DETECTED → STOP (No)

**Fig. 4**: Communicate on the selected Channel → Monitor Interferences → Interferences Detected? → Send ACS Request to Coordinator
algorithm used for the selection of the communication channel in a ZigBee network, after the system and the ACS algorithm are initialized. Thus, each node within the network consecutively scans all 16 channels by performing ED (Energy Detection) measurements for each channel in order to determine their occupancy level. Since the ED values can vary sporadically in time, each node will perform a total of 64 consecutive readings that will be used in the calculation of the arithmetic mean for each individual channel.

Each average ED value calculated is saved in a vector that has 16 positions for each channel and an additional position that stores the network depth of the node. For instance, the coordinator node will have a network depth of 1. The vector is sent on the communication channel (before the ACS procedure) to the network coordinator node which will perform the selection of the optimum communication channel.

Fig. 4. Flowchart of the proposed adaptive channel selection algorithm.

Fig. 5 presents the logical diagram of the coordinator node. For each node to contribute to the optimal channel selection according to certain priorities, the coordinator will perform a weighted average calculation for each channel. The weight of a node $i$ is calculated by means of (1) where $NN$ stands for the total number of nodes, and $ND$ is the network depth

$$p(i) = NN - ND_i + 1.$$  

Thus, the measured ED value for an $n$ channel can be calculated by means of (2) and the network best channel (NBC) by means of (3):

$$ED\_channel(n) = \frac{\sum_{i=1}^{16} ED(i) \cdot p_i}{\sum_{i=1}^{16} p_i}$$  

$$NBC = \left\{ \min(ED\_channel) \right\}$$  

This channel selection algorithm is based on the idea that each link between two nodes must contribute differently in deciding the optimal channel selection. Thus, an average weight is introduced, calculated according to the network depth of the nodes. The nodes located at the extremity of the network (at a higher network depth) will have lower priority in terms of the channel selection than those which have a lower network depth, thus implicitly enabling links that are more important for the network operation. The coordinator will select the optimal operating channel which has the lowest value of the calculated weighted average. The novelty of the suggested algorithm consists in the fact that each node in the IEEE 802.15.4 network contributes to the global selection of the optimum channel with the highest performance level.
IV. PERFORMANCE EVALUATION

In order to validate the performance of the suggested ACS algorithm, a series of tests have been conducted. Thus, seven 802.11g routers have been installed, operating on the 2.4 GHz frequency bandwidth. Table I shows the operating channels of each AP and the related signal strength.

The ZigBee module used in the measurements is Jennic JN5148. An application was thus developed to perform 64 ED measurements for each channel, to calculate the arithmetic mean and to send the obtained values to the coordinator node. Two nodes were used in the tests, located at a distance of 40m. Fig. 6 shows the signal strength values received by the coordinator node (node A) and by the second node (B) for each channel.

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Channel Number</th>
<th>Signal Strength [dBm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>AP1</td>
<td>11</td>
<td>-59</td>
</tr>
<tr>
<td>2.</td>
<td>AP2</td>
<td>9</td>
<td>-61</td>
</tr>
<tr>
<td>3.</td>
<td>AP3</td>
<td>1</td>
<td>-72</td>
</tr>
<tr>
<td>4.</td>
<td>AP4</td>
<td>2</td>
<td>-71</td>
</tr>
<tr>
<td>5.</td>
<td>AP5</td>
<td>3</td>
<td>-87</td>
</tr>
<tr>
<td>6.</td>
<td>AP6</td>
<td>2</td>
<td>-83</td>
</tr>
<tr>
<td>7.</td>
<td>AP7</td>
<td>2</td>
<td>-87</td>
</tr>
</tbody>
</table>

Fig. 7 presents the energy detection values measured by the coordinator node and by the second node. The ZigBee channels, which are less affected by interferences, are those which have the lowest ED values, i.e. the channels 26, 16 and 17, as expected, since the overlapping with an IEEE 802.11 channel doesn’t occur.

As can be observed, the RF environment is more congested in the vicinity of the second node. Thus, the channels with the lowest average ED values measured are channels 18, 17, 16 and 26.

The coordinator node receives the ED values after the conducted measurements and performs the processing operations in order to determine the optimum operating channel. Fig. 8 shows the values obtained after processing the values and determining the weighted average and the selection of the channel with the lowest ED value.
The recommended channels are 26, 17, 18, and 16. The coordinator subsequently selects the operating channel number 26 that has an ED level of approximately 42. Thus, the proposed ACS algorithm enables the optimum selection of the channel and thus ensures a high performance level. The channel will subsequently be recommended for implementation in a street lighting monitoring and control system.

V. CONCLUSIONS

This paper introduces an algorithm for selecting the optimal operating channel for an environment that is severely affected by interferences. The algorithm can be implemented when a tree network topology is used. In order to detect the interferences, an ACK/NACK algorithm is employed. When interference is detected, each network node contributes to the selection of the optimum operating channel. The ACS algorithm can be initialized when a tree network topology is used. In order to validate the performance of the suggested algorithm, a series of tests have been conducted. Even when the RF environment is congested by the presence of seven 802.11 access points, the coordinator is able to make the selection of the optimal channel for the entire network.

REFERENCES


Fig. 8. Energy detection after processing.