Customer Specific Wireless Network Solutions Based on Standard IEEE 802.15.4

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Abstract

The standard IEEE 802.15.4, which is published since 2003, is used as a base for many wireless network solutions [1]. The most popular wireless network is ZigBee™, which offers lots of additional functions like mesh network, and interoperability [2]. Looking on a wide range of different markets most appeared problems can be solved by very simple point-to-point or point-to-multipoint connections as a simple cable replacement. Only a very small number of problems really need ingenious and comprehensive solutions. It is not necessary to use complicated and expensive network layers if many integrated functions have to be shut off for the specific application. Therefore it is necessary to offer a modular build and problem orientated solution which is cheap, easy to handle and individually made to solve the specific problem with the opportunity to be extended on demand.

In this paper different network solutions based on standard IEEE 802.15.4 are introduced. Different application examples are discussed to find out the adequate solution for each problem. The focus is set to help finding out the specific solution for individual problems rather than compare the maximum reachable parameters of the different network solutions. Only systems based on the standard IEEE 802.15.4 are discussed because of its wide possibilities of different functionality and features.

1.   Introduction

According to the fast rising number of wireless personal area networks (WPANs) many users do not really know which solution will be the best for their particular application. The general requirements on these networks, especially of wireless sensor networks (WSN) in industrial applications are simple to define. It should improve the asset by rising the process efficiency, maintainability and productivity. These WSNs allow much wider usage than wired solutions and can unlock tremendous value in savings, improved quality and system uptime [6].

Regarding the individual demands of the problems which will be solved with WSNs the results seem to be comparable but the way to reach them are very different. In fact, each problem to install a wireless sensor network needs a customized solution. It is not possible to copy an existing WSN to different applications or surroundings without individual adaptations. Many network solutions offer lots of integrated functions, which will be not necessary on specific individual applications. This may lead to disadvantages. Often it is better to use simple than complicated networks to reach better performance of the system. Therefore different network topologies and sample applications are presented to help finding out the specific solution for the individual problem.

2.   Common Network Topologies

2.1.   Point-to-point

This network is the easiest topology. No address algorithm and no routing algorithm have to be implemented to create the communication between two points. All network solutions based on standard IEEE 802.15.4 can implement point-to-point topologies. Also similar protocols like the Freescale SMAC are well suited to solve such problems [4]. Remote controls mostly are simple point-to-point networks (Figure 1). Often, they are one-directional and not bi-directional.
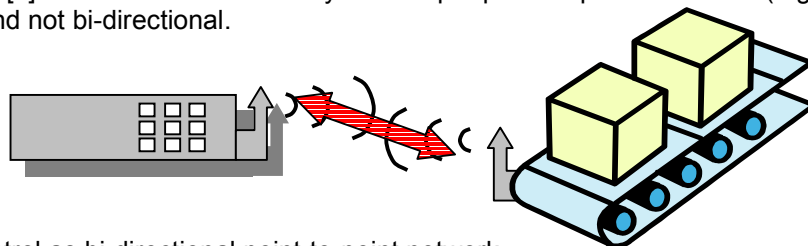

Figure 1: Remote control as bi-directional point-to-point network

Note: **IEEE**® is the registered trademark of the Institute of Electrical and Electronic Engineers
ZigBee™ is the trademark of the ZigBee Alliance.

2.2. Point to Multipoint

This topology is also called star network because there always exists a central node with multiple nodes around. The standard IEEE 802.15.4 is well suitable to build such networks. It is necessary to have a PAN coordinator, which starts the network and allocates addressed for each node. The maximum number of nodes is limited only by the radio channel capacity, which means the commonness of the transmitted packets, and the capacity of the coordinator's associated device list. In most industrial applications, WSN have a star topology because every node can directly communicate with the central point (Figure 2).
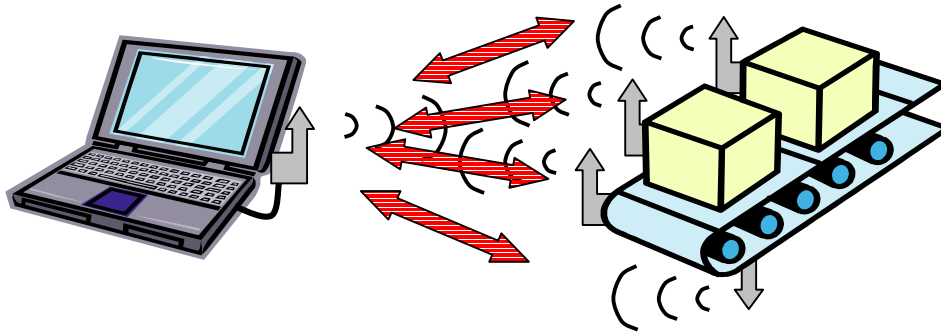

Figure 2: Wireless sensor network in industrial application

2.3. Cluster Tree

The cluster tree topology can be implemented by multiple star networks where the central nodes itself are connected as multiple star networks too. The structure is strong hierarchical with nodes in multiple layers. Each node is connected with maximum one node in the upper layer, no node in the own layer and can be connected with multiple nodes in the lower layer. This type of network needs corresponding routing algorithms to realize the data transfer throughout multiple layers. So the data always will be transferred to upper or lower layers and never in between a layer itself (Figure 3). For IEEE 802.15.4 the data transfer using multiple hops is easy and fast because each node can interact only with its pre-defined parent nodes and child nodes.

In most industrial applications all data is sent from or to a central point. Therefore, the cluster tree topology is very useful for larger networks. The disadvantage can be found if any node fails. Here the complete tree behind this point of failure is cut off the network.
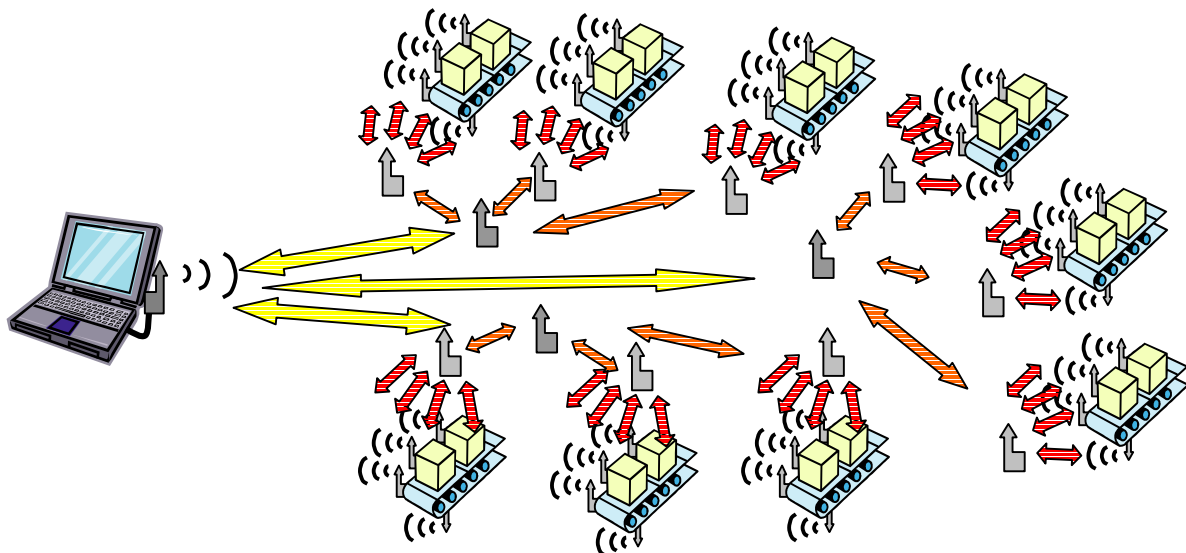

Figure 3: Cluster tree network in industrial applications

2.4. Mesh network

There exist several definitions of meshed networks. The main features of these different definitions are:
- a self configuration of the network
- non predefined fixed data routes
- self healing and self organizing network

It is often also called an 'Ad-hoc Network'. On the one hand there exist full meshed network topologies, which means every node is directly connected to each other node. On the other hand if the nodes are connected to those other nodes which they exchange most data it is called partial mesh topology (Figure 4).
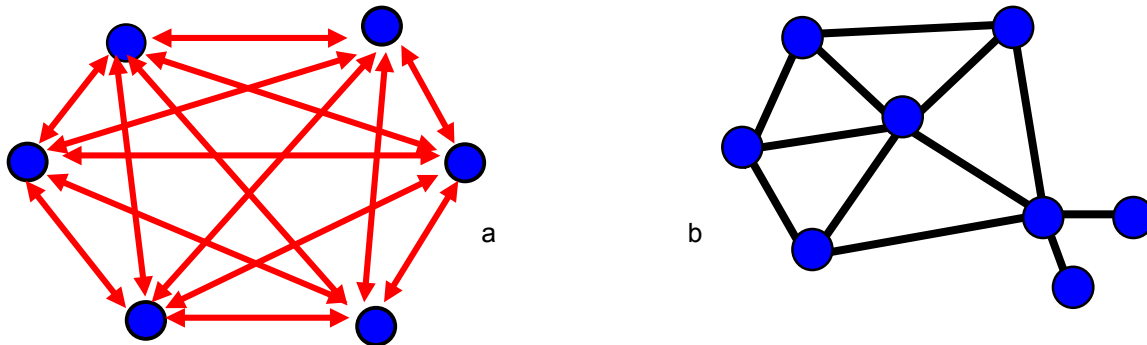

Figure 4: full meshed network (a) and partial meshed network (b)

It is clear, that a full mesh topology only can be implemented with a small number of nodes. Therefore most mesh network solutions based on standard IEEE 802.15.4 are partial mesh topologies. This causes complicated routing algorithms to realize reliable data transmission. An ad-hoc routing algorithm controls how nodes come to agree which way to route packets between devices in an ad-hoc network. Nodes do not have a priori knowledge of topology of network around them - they have to discover it. The basic idea is that a new node (optionally) announces its presence and listens to broadcast announcements from its neighbors. The node learns about new near nodes and ways to reach them, and may announce that it can also reach those nodes. As time goes on, each node knows about all other nodes and one or more ways how to reach them [5]. These principles can be divided into two main algorithms. Even there exist lots of routing principles main routing algorithms are pro active (table driven) or reactive (on demand driven).

Pro-active (table-driven) routing algorithm
These algorithms maintain a fresh list of destinations and their routes by distributing routing tables in the network periodically. The main disadvantages of such algorithms are:
- bandwidth wastage in transmitting routing tables
- wastage in maintaining routes that are never going to be used in future
- simulations have shown that several proactive algorithms like DSDV are never able to converge in a large network

Reactive (on-demand) routing algorithm
The protocol finds the route on demand by flooding the network with Route Request packets. The main disadvantages of such algorithms are:
- delay in route finding
- excessive flooding can lead to network clogging

3. Competing parameters for wireless networks

For each application it is necessary to prove the following parameters (Figure 5). Therefore lots of problems in industrial wireless networks can be covered with simple and well-adapted solutions.
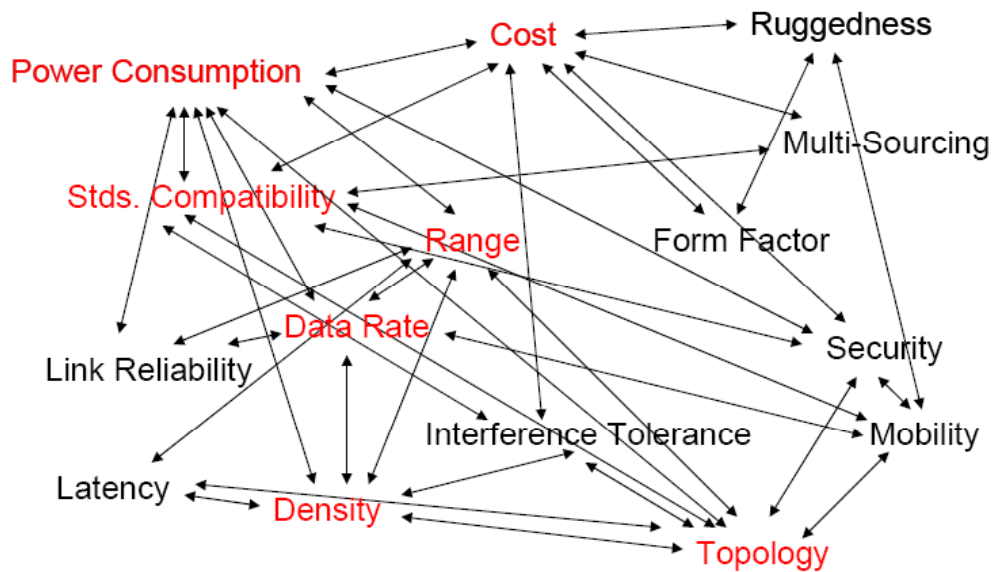
Figure 5: Competing parameters for wireless networks [6]

To reach higher range and higher reliability of the transmission between two nodes power amplifiers can be used. But this leads also to higher power consumption. So, routers have to be installed. Every additional hop needs a certain time, so the latency is rising and the reliability decreases. So, for every application an individual solution has to be found out to get the best system to solve one's problem.

4. Adaptive cluster tree network

To include the demands of the centralized control in industrial applications with the advantages of an ad hoc network the adaptive cluster tree network was developed [3]. It is optimized for the usage with the ZEBRA Module from senTec Elektronik GmbH, based on the chip set ZRP1 from Freescale Semiconductor [4].
The idea is to use the alternative routes only if the standard connection is interrupted by any point of failure (Figure 6).
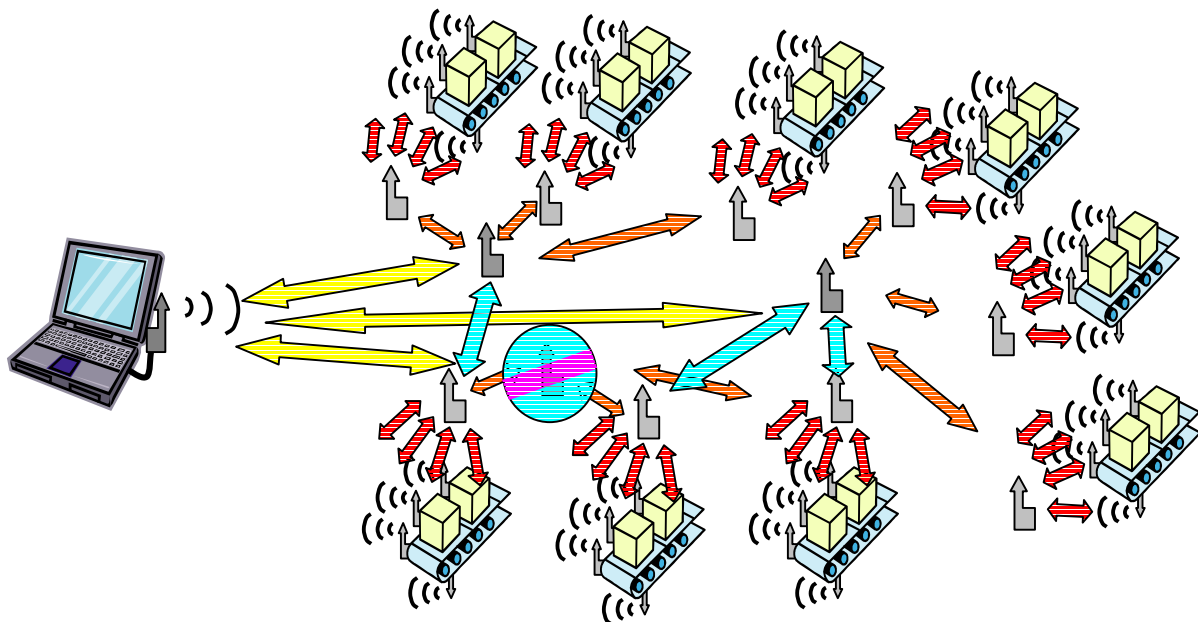

Figure 6: Adaptive cluster tree network with alternative routing

Two potential ways of combining the hierarchical and the reactive routing algorithms are possible:

- The nodes send in regularly intervals a broadcast for neighbors in upper layers, lower layers and in the same layer. Interesting nodes are stored in a neighbor list of each node to find an alternative route on demand. This leads to a faster transmission if the standard route is interrupted.

- Only in the case of interception the broadcast for neighbors is sent. Here, it takes much more time to find the alternative route, but resources and energy is saved.

Both possibilities need a simple and fast way to discover which node is placed in which position and layer of the network (Figure 7).
This can be done by the addresses of each node in the fastest way. No additional information from the coordinator or from the neighbor devices is necessary. Each node has a priori information about the network topology and the position of all neighbors.
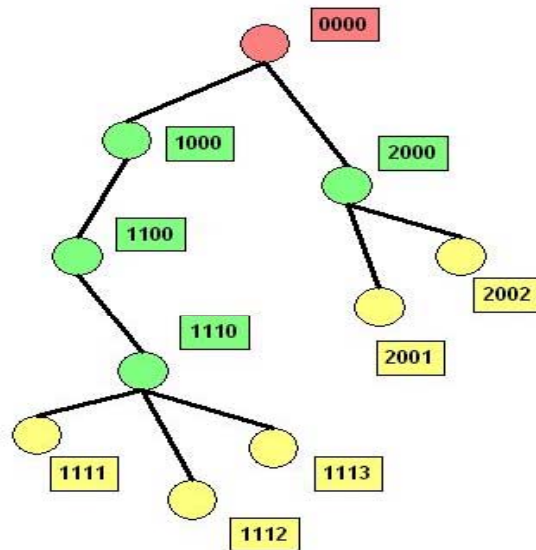

Figure 7: Network addresses with information about the position and the layer

In case of the alternative route the broken link will be reported to the coordinator. So it is easy to repair the network from this central point.
If one node falls out, the packets were send to the neighbors of the same layer of the single point of failure. So the data transfer can be continued on an alternative path. The routing is still strong hierarchical and all data packets still will be send to or from the coordinator. This is still very important in industrial applications because all data have to be collected and analyzed for documentation. With the additional feature of the adaptive cluster tree network the reliability of the system increases enormously.
It is quite different from mesh networks because it is not possible to send data between nodes without including the coordinator. The advantage is the simple and fast routing algorithm. First measurements show latency times of ~4.5 ms for one hop within the adaptive cluster tree network. Compared to typical mesh networks on the same hardware platform which takes ~8.9 ms for one hop [7] it is nearly 50% faster.

5.   Frequency agility or frequency hopping

Once a network has started, several parameters are fixed. Also, the frequency channel, which is used by the network, usually is determined at the beginning during the formation of the network, after an energy detection scan of the surrounding. The actual standard IEEE 802.15.4 does not foresee any change of this predetermined frequency channel. If any interference starts troubling the network later on, it is not possible to switch to another channel. Especially in larger networks with external interference far away from the network coordinator, this can lead to great problems. Now, some development is ongoing to solve this problem by a frequency change during network operation. There are two principles possible:

- synchronous change of the radio channel for all nodes of the network
- asynchronous change of the frequency only when link quality is poor

The frequency changing feature needs to be implemented on a higher layer than the standard IEEE 802.15.4 MAC – e.g. on the network layer. Once this feature is included, it makes the adaptive cluster tree network a strong and reliable tool for industrial applications.

6. Conclusions

Every application for WPANs has to be adapted individually. For wireless sensor networks in industrial applications it is often necessary to use one central point which collects all relevant data and controls the network as well as the application. Therefore, a cluster tree topology seems to be a good solution. The packet transmission can be realized very easy and fast. To decrease the reliability in the case of failures, the adaptive cluster tree network has been developed. The alternative routes can be discovered very easy because all information for the position in the network is given in the addresses of the nodes. It is a comfortable solution for industrial applications in combination with senTec's ZEBRA Module.

If the possibility of frequency changing is included, also external interference, which appears later after network initialization, will not disturb the data transmission seriously.

7. Sources

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8. Authors

Michael Binhack was studying microelectronics and sensor technologies at the Technical University in Ilmenau from 1993 to 1998. Since 1998 he is developing active and passive wireless sensor systems. Today he is responsible for projects dealing with wireless sensors and wireless sensor networks based on standards IEEE 802.15.4 and ZigBee at the senTec Elektronik GmbH.

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