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Wireless Fire Protection Technology

Highly reliable mesh technology for safe wireless transmission combined with the unique ASA*technology* for highest detection reliability.

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The SWING (Siemens Wireless Next Generation) fire detection system, as presented in this paper, is a wireless fire detection solution which offers a high level of reliability and flexibility. SWING combines a failsafe wireless network with the patented **ASA***technology*™ (ASA = Advanced Signal Analysis) from Siemens for optimal fire detection. Fire detectors with **ASA***technology* ensure the earliest possible detection of all fires. Being immune to deceptive phenomena like steam, dust or smoke, they provide excellent detection reliability and protection against false alarms in every environment, from clean to harsh. In fact, they are so reliable that even a Genuine Alarm Guarantee* may be provided.

The SWING wireless system is especially suitable for use in locations, in which the wiring of fire detectors is impossible or undesirable. SWING is based on mesh technology, which maximizes communications redundancy and thus matches the security and reliability of a cable-based solution. Within the mesh network, each wireless device communicates with the adjacent devices. This means that at least two redundant paths are available at any time for transmitting information. To further increase reliability, each device has two frequency bands with multiple channels. In the event of interference, the network “repairs” itself by automatically attempting to change channels and/or frequency bands or forward information via an adjacent device. This ensures that all available information always reaches the gateway and, ultimately, the fire control panel.

Wireless fire detection is the ideal solution for rooms or buildings of historical value, with aesthetic or architectural restrictions, or for temporary installations. Thanks to wireless technology, devices can be quickly and freely positioned and repositioned. This facilitates planning, allows for cost-efficient installation and offers a high level of freedom and flexibility, should the room usage or building structure change in the future.

Contents

Introducing SWING

> "SWING creates the wireless loop required for transmission robustness and responsiveness."

Motivation
In this paper, we would like to provide an overview of SWING, the Siemens Wireless Next Generation product portfolio, as well as some information concerning the underlying technology. We developed SWING to improve previous wireless fire detection systems. Besides the advantages concerning communication technology – moving from simple star topologies to multihop mesh networking – we aimed to simplify the commissioning and maintenance process, so as to require a minimum of human interaction.

In the following section, we discuss the main regulatory requirements for wireless fire detectors, followed by a detailed discussion of the underlying technology. We conclude the paper by summarizing the primary benefits of SWING.

Historical Background
In the 1980's, the first solutions for wireless sensor networks (WSNs) were proposed in research, which resulted in the first products being introduced to the market in the early 1990's. Over the years, these wireless sensor networks not only changed in terms of target applications (from military use and environmental monitoring to e.g. fire detection), but also from a technological point of view.

The earliest wireless fire detection solutions were mainly based on a simple star network topology (A). Hence all detectors were directly connected to a gateway. These networks suffered from interference. If a radio link was not available, the affected smoke detector was also not available. In addition, these systems only offered limited radio ranges.

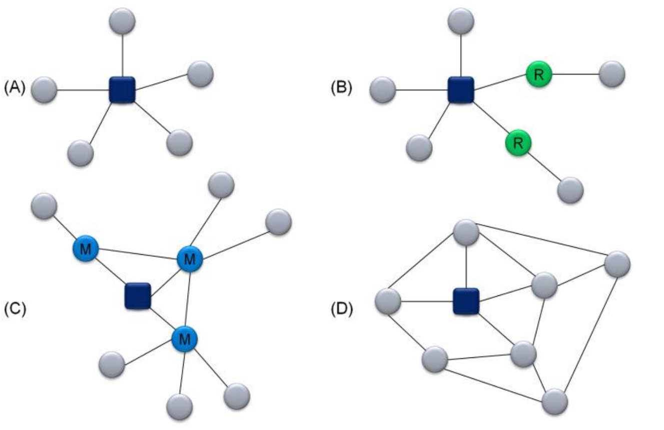

Figure 1: Four different topologies of wireless sensor networks (Star (A), Extended Star (B), Mesh Backbone (C), Full Multihop Mesh (D))

To overcome the range limitation, wireless sensor networks based on the KNX RF standard [9], for example, used repeaters (B). However, these extended star networks are still not robust against radio interference as they rely on a single link between the detector and the gateway.

Instead of extending the range of a WSN, other systems improved the robustness of the radio transmission by enhancing the star topology by routing messages through neighboring devices in case of link failures between the detectors and the gateway. This represents the simplest version of a mesh network.

Combining repeaters and the use of neighboring devices for routing messages leads to multihop mesh networks. Today, this topology is state-of-the-art. However, there are several nuances. ZigBee-based networks typically offer a well-connected backbone infrastructure with mains powered devices forming a mesh network. Battery-operated devices may connect to one of these backbone elements, each forming a star topology network (C).

Finally, it is possible to use a multihop mesh topology, in which all devices are well connected to their neighbors. In a multihop mesh network, some devices may reach the gateway only through other devices, but it can be reached over multiple paths. SWING uses such a network topology (D), having all devices but the gateway battery-operated and therefore truly wireless. The multihop mesh topology allows the system to cope with failures of single devices or radio links as there always exists at least a second option to reach the gateway. Hence, compared to the wired world, we could think of stub wiring for previous systems, whereas SWING represents a wireless loop.

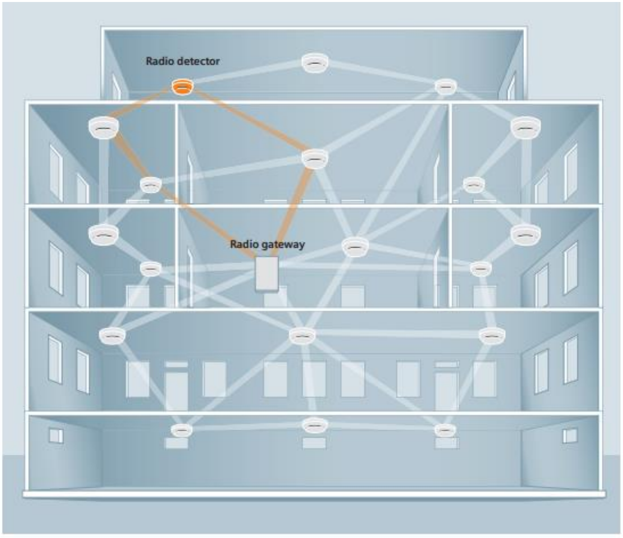

Figure 2: Range of SWING system in a building

Simple Installation

Another important aspect with regard to wireless fire detection systems consists of the ease of commissioning. In the early days, the systems offered many pitfalls during installation and commissioning. Especially when compared to wired fire detection systems, wireless systems required experts for commissioning.

When we developed SWING, we did not only aim at increasing the range and robustness of the radio communication connections by moving from simple star topology networks to a multihop mesh network, but also worked on simplifying the installation and commissioning of the wireless detectors in the field, while keeping the installation process fast and reliable.

Fire Detection

Besides range and robustness of the wireless network, and the simplicity of installation, a third important part for a wireless fire detection system is actually the performance of the fire detector itself. The use of batteries limits the amount of energy that is available for the fire detection. In the first wireless fire detection systems, the fire detection part was rather simple, mostly being simple optical smoke detectors.

For SWING, we used the standard **ASA***technology* dual optical and heat detector as a basis and started to lower the energy consumption dramatically, ending up at a 10% of the consumption at the same performance as for a wired fire detector [6].

Fire Detection is a Regulated Business

Challenges in EN54-25

The EN54 series includes all the relevant regulations for commercial fire detection systems in Europe. As there are quite a few differences as compared to standard wired fire detection, a special part of the series is devoted specifically to wireless fire detection.

The main regulations for wireless fire detection are defined in EN54 part 25 [8]. From this text, we can summarize the following main requirements stipulated by the regulations:

- Alarm Transmission Time: the maximum time allowed between detection of a fire to signalization at the control panel is 10 s
- Monitoring: missing or malfunctioning devices have to be reported to the user at the control panel within at most 300 s after the error occurs
- Battery Lifetime: batteries used with wireless detectors shall last for at least 3 years of operation

All of the above points are very challenging. When developing a wireless fire detection system, it is very important to find the balance between minimal energy consumption, device monitoring to detect failures, and fast alarm times. As SWING may be used with a standard field bus, alarms have to be transmitted in around 5 s from detectors to gateway. The remaining 5 s are needed for the alarm transmission from the gateway to the fire control panel via the wired field bus. The easiest way to achieve this goal would be to always check the environment for alarms and immediately transmit an alarm to the gateway as soon as it is detected. Following such an approach would fulfill the requirement concerning alarm transmission time, but would fail concerning battery lifetime, as keeping the transmitter switched-on all the time results in battery lifetimes of days instead of years.

More elaborate protocols are therefore required, which have a special focus on low energy consumption when designing wireless protocols for alarm transmission and monitoring, and low energy smoke detectors. Wireless sensor networks use most of their energy when either transmitting or receiving data. It is essential that the transmitter and receiver are switched to an energy-saving state (e.g. sleep mode) whenever possible.

The challenge is to design an alarm transmission protocol in a way that alarms are reliably transmitted to the gateway within the foreseen time limit of 5 s, while using as little as possible energy. The same principle holds true for the network monitoring used to detect defective devices in the wireless network. We want to monitor as little as possible while still being (a) able to fulfill the regulation of signaling defective devices within 300 s and (b) being robust against temporary network outages that should not affect the overall system performance.

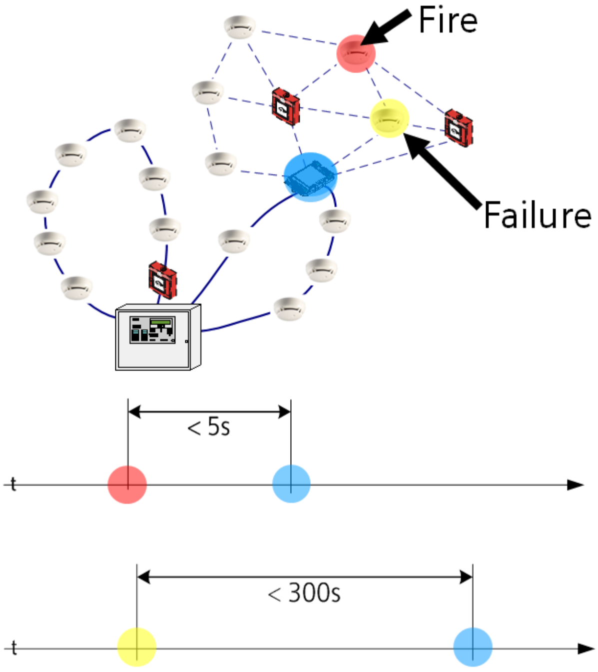

Figure 3: Timing considerations for a regulated wire-less fire detection system

In the following section, we will discuss our protocols for alarm transmission and monitoring in more detail.

Besides the discussed EN54-25, we of course also have to adhere to all relevant regulations for manual call points (EN54-11) and fire detectors (EN54-5, EN54-7). This paper, however, focuses on the wireless part.

Overall, regulations were one of the main drivers for the design of both the wireless communication protocols and the manual call point or fire detector application.

A white paper issued by Siemens.

SWING – Basic Principles

The SWING system design is based on three primary objectives.
All protocols and functionality are designed to meet these three goals in the best possible way.

- **Robustness** – network can handle link and node failures
- **Reliability** – messages all arrive timely at their destination
- **Low Energy** Consumption – battery lifetime of more than three years

In the following section, we discuss a selection of mechanisms and protocols implemented in the SWING system. We start with low-level radio communication and incrementally extend the application range of the discussed topics towards network wide communication.

Radio Communication Protocols

The three principles mentioned above are first considered for low-level local node-to-node communication. Due to energy saving reasons the radio on-time of receiver and sender node must be kept as short as possible. Nevertheless, a node must be accessible within a reasonable time.

WiseMAC

The local node-to-node communication is handled by the so called Medium Access Control (MAC). The following picture shows a selection of well-known MAC protocols.

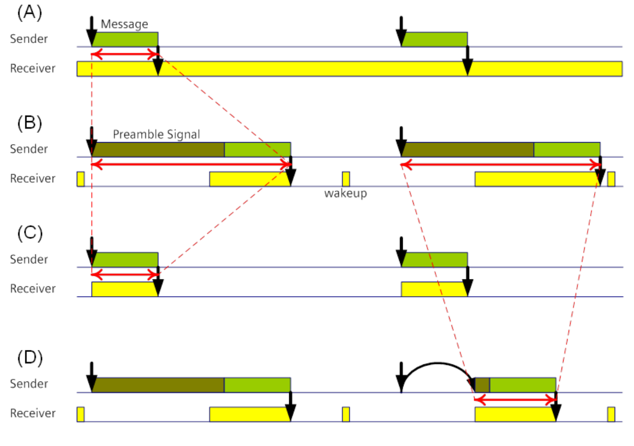

Figure 4: MAC Protocols: "always on receiver" (A), "low power listening" (B), TDMA (C), WiseMAC (D)

(A) "always on receiver": receiver node can be reached at any time. Sender node can operate at minimal energy because no preamble (wait on receiver) time is needed.

(B) "low power listening": receiver node only can be reached periodically. Sender node transmits a preamble signal for a receiver period duration to ensure that a receiver on-time is met.

(C) "TDMA": receiver and sender node are perfectly synchronized in a Time Division Multiple Access (TDMA) scheme.

(D) "WiseMAC": improved low power listening MAC using wakeup time learning and drift estimation.

For a distributed, bidirectional system like SWING the options (A), (B), and (C) are no solutions. (A) and (B) require too much energy consumption either for the receiver or the sender node, and (C) requires globally synchronized nodes, which is a complex issue in a distributed system.

Thus, SWING uses an improved low-power listening MAC layer protocol called WiseMAC (D).

In WiseMAC nodes are not permanently receiving, but switch on their receiver only every 1.5 s. All nodes have the same wakeup interval. If during wakeup they detect a message on air, they continue receiving the message, otherwise they go back to sleep immediately.

With each transmission, a node learns the wakeup time of the communication partner relative to its own wakeup time. This allows the sender to time the next transmission on the wakeup time of the receiver node and to reduce its radio on-time significantly.

The nodes do not have a common time base; hence the wakeup times will drift relatively to each other over time. The farther the last communication lies in the past, the less accurate the sender can calculate the wakeup time of the receiver. To overcome this uncertainty, the sender node uses two mechanisms:

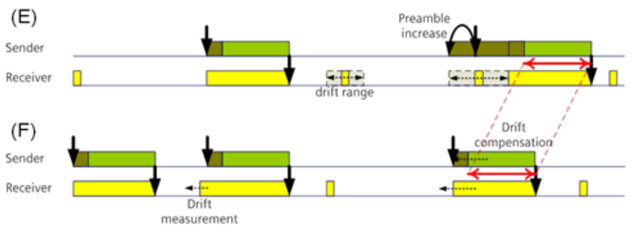

Figure 5: WiseMAC concepts: Preamble time increase (E) and Drift estimation (F)

(E) Increasing the preamble time to cover the whole uncertainty range of the receiver's wakeup time

(F) Estimation of the drift velocity of the receiver's wakeup time based on two consecutive transmissions.

The MAC provides the basis for any communication. On top of that, there are mechanisms in place to handle the frequency band and transmission power usage, summarized as link maintenance.

Link Maintenance

The SWING system operates in the Industrial Scientific Medical (ISM) frequency band within 433 – 434 MHz and 868 – 870 MHz dedicated for short range devices. 47 channels are available within these frequency ranges, of which each node selects one as its receiver channel. The own receiver channel is announced to neighboring nodes and selection takes placed based on the already known channels of neighboring nodes. This evenly distributes the available spectrum regardless of the number of communication partners in range, thus resulting in minimal interference and/or message collisions.

The following picture shows an exemplarily snapshot of simultaneous communication on several channels.

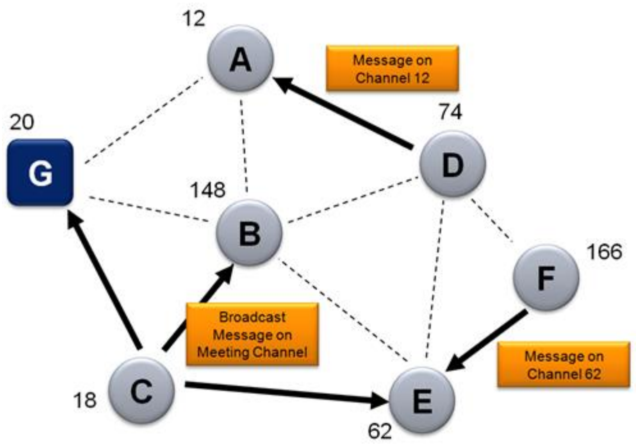

Figure 6: Message transmission principles for broadcast and unicast messages

The second mechanism towards minimal interference and, consequently, low energy consumption strikes the adaptation of transmission power. On any sent message, the sender node receives a confirmation message containing the feedback of the receiver node based on the received signal strength. Thus, the receiver node advises the sender node, as to whether the transmission power should be lowered or increased for the next message, respectively.

Lower transmission power means less energy consumption on the one hand and interference of fewer nodes not involved in the transmission. Both measures serve the purpose of longer battery lifetime.

On MAC and link maintenance level, the main focus lies on energy efficiency principle. On higher levels, more emphasis is placed on the robustness and reliability principles.

DWARF – Delay-aWAre Robust Forwarding

The end-to-end communication towards the gateway as it is used for alarm messages, for example, is handled by the DWARF protocol. The picture below depicts an example of end-to-end transmission from a peripheral node towards the gateway.

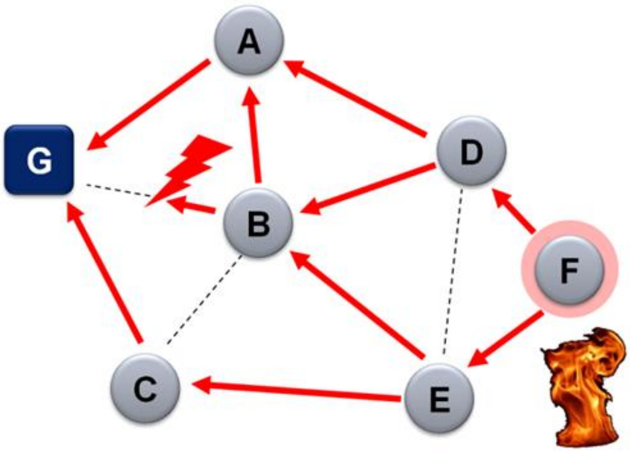

Figure 7: Message Transmission in case of a Fire Alarm

DWARF messages are transmitted over multiple paths from the sender node to the gateway. Every node receiving a DWARF message forwards the alarm message over multiple paths to the neighboring nodes that can be reached first, i.e. with the closest wakeup time. Nodes closer (= fewer intermediate nodes) to the gateway are preferred. Duplicate messages are recognized and discarded on the way or finally at the gateway. In case of failed transmission, the sender node simply carries on by selecting the next reachable node.

DWARF allows finding the fastest way to the gateway (reliability) and overcomes transmission failures without time consuming end-to-end retransmissions (robustness).

Furthermore, every participating node simply requires local information, and thus no global network information needs to be maintained (energy).

Beside alarm transmission, SWING's core functionality also lies in the network monitoring.

DiMo – Distributed Monitoring

The monitoring differs from the alarm transmission in the way that a faulty or unconnected node cannot autonomously notify others about this state. Instead, it must be recognized by other nodes. SWING uses the DiMo concept for network monitoring.

The DiMo has two key characteristics:

(A) Local node monitoring

(B) Centralized management of the monitoring states of each network participant at the gateway

Local node monitoring is set up and maintained by each node individually. Every node selects two nodes as monitoring nodes. The node that wants to be monitored sends regularly alive messages to the monitoring nodes.

The monitoring nodes inform the gateway, as to which node they monitor by registering this node. From now on, the monitoring nodes keep track of the alive messages and inform the gateway in case of missing alive messages. If a node can no longer reach one of its monitoring nodes, the node selects a new node to be its monitoring node.

The following picture shows the actions related to the local node monitoring.

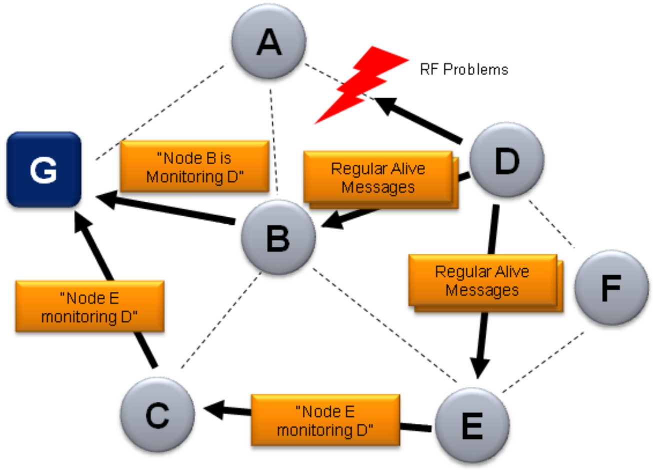

Figure 8: Monitoring principle in case of detected radio link problems

Centralized management is performed at the gateway only. The gateway keeps track of all nodes in the network and of their monitoring nodes. To do so, the gateway maintains a monitoring status table as shown in the following figure.

Node	Monitoring Node	Monitoring Node
A	G	B
D	A	B
F	D	E

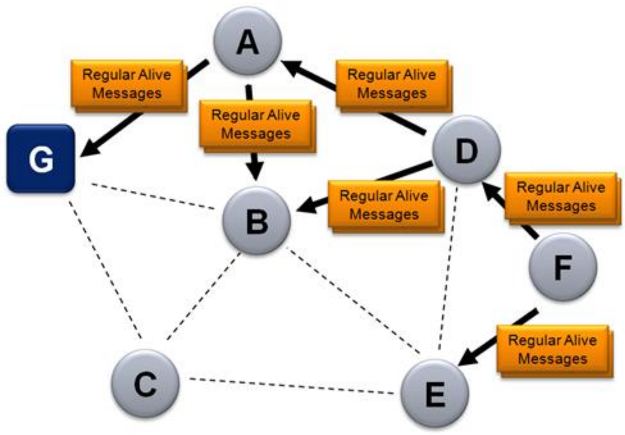

Figure 9: Monitoring according to monitoring table in normal operation mode

As long as there is at least one monitoring node for a certain node, this node is in monitored state. If there is no monitoring node registered at the gateway for a certain node at all, this node is marked as missing.

Whenever a node is missing at the gateway, the gateway checks whether this node is a monitoring node for other nodes. If so, it is deleted from the monitoring status table as a monitoring node.

By separating local monitoring from network monitoring we reduce the end-to-end communication to a minimum, thus targeting the low energy principle. In addition to this, the centralized monitoring management provides up-to-date information for message routing from the gateway to any peripheral device in the network.

DSR – Dynamic Source Routing

A distributed system like SWING has to be able to cope with network topology changes at any time, i.e. global network topology information is outdated sooner or later. For directed messages from the gateway to a single node, we therefore use an ad hoc route composition protocol, the so called Dynamic Source Routing (DSR).

The monitoring management data contains two reliable and up-to-date links to two neighboring nodes for each node. Based on these links multiple routes can be composed on which the destination node can be reached. The route finally selected for message transmission varies for each message, mainly to distinguish between the length of the routes and for energy balancing.

Each of the topics described thus far serves at least one of the main goals listed at the beginning. These system-internal goals are important for the purpose of a well-balanced, consistent, and optimized system, but are rather technical. In the following section we therefore focus on the benefits of the SWING system for the user.

Benefits

The applied protocols and concepts in the SWING system and the achieved optimization level result in a flexible and reliable wireless fire detection system. Commissioning and maintenance is fast and simple compared to previous and current wireless solutions, which makes life significantly easier for installers and maintainers. The system can be used for applications in various and even changing environments due to its robust and reliable design.

Easy Maintenance and Commissioning

The SWING system was especially designed to make life easier for planners, installers, and maintainers. In addition to the advantages provided by the lack of cables, the network commissioning itself is very fast.

Planning is carried out in advance following an easily manageable set of installation guidelines to define how many devices are required and where they need to be positioned. Thus, no measurements (e.g. of the radio characteristics) are required on site.

By entering a dedicated commissioning mode at the gateway, the network maintenance process is temporarily accelerated. This allows for smooth integration of new devices into the network and rapid development of new communication links.

Any device installed provides feedback within a reasonable time on the network integration, thus directly confirming the current status to the user. Therefore, no extra equipment (e.g. PC software tools or special radio equipment) is required to install the network. Furthermore, multiple devices can be installed in direct sequence without having to visit the gateway in between.

Similar use cases exist for removing and replacing devices, or changing batteries.

For advanced maintenance cases, a PC software tool is available that allows for collecting information about the wireless network and device status. In case of unsatisfactory behavior or for reporting purposes, the tool can be used for system analysis.

Enhanced Robustness

During normal operation, the SWING system constantly monitors and maintains the communication links. This serves to delete non-functioning or obsolete links and initiate new connections. This constant process is known as self-configuring and self-healing functionality.

The speed of adaptations to changes is reduced in normal operation compared to the commissioning mode. This is the result of the fewer changes to be expected.

For enhanced robustness, we introduced the wireless loop, i.e. we always have two node-disjoint paths from any device to the gateway. Doing so, we can tolerate the failure of a link or even a whole neighboring device and are still able to transmit the alarm or trouble messages from the wireless detectors to the control panel (similar to a shortcut in a wired system with loop topology).

To cope with the presence of other band users, SWING is enabled to use 47 channels on two frequency bands. In case of a disrupted channel or band, the communication frequency is changed automatically to a more suitable channel. Every node decides on its own whether the receiving channel performs sufficiently or else should be changed without dependencies on other devices.

ASA*technology* Detectors with the Genuine Alarm Guarantee*

ASA*technology* is a unique technology from Siemens that converts signals into mathematical data, which are compared with programmed values in real time using intelligent algorithms. The special signal analysis process is very reliable in preventing false alarms caused by on-site deceptive phenomena such as steam, tobacco smoke or exhaust emissions.

The SWING detector combines the experience of the **ASA***technology* known from wired devices with enormous improvements towards low power operation, required for a battery-powered device.

Thanks to the unique deception-free **ASA***technology* [10] from Siemens, the SWING detector is more reliable than a conventional wireless smoke detector. By simply choosing the application-specific ASA parameter set, it can be optimally adapted to the current environmental condition.

To prove maximum reliability of the detectors with **ASA***technology*, an industry first guarantee against false alarms may be offered, ensuring excellent detection reliability with immunity to deception. *

Summary

In this paper, we have presented SWING, the solution from Siemens for wireless fire detection based on mesh technology.

Mesh technology helps maximize communications redundancy and thus matches the security and reliability of a cable-based solution. For example, at least two redundant paths are always available for transmitting information, because all wireless devices within a network communicate with the directly neighboring devices. Reliability is further enhanced, as each device has two frequency bands with multiple channels. This means that, in the event of a disruption, the network can repair itself by automatically changing channels and/or frequency bands. However, information can also be forwarded to a different adjacent device. The advantage here is that no information gets lost; it always reaches the gateway and ultimately the fire control panel.

Mesh technology is also a great choice for setting up large wireless networks. As every connected fire detector communicates with its neighboring devices, the central gateway doesn't have to be in direct radio contact with each and every detector. Thus, one network with a single gateway can have a radius of up to 60 meters and span up to five floors.

Furthermore, a SWING network is fast and easy to install because there's no cable work involved. It also offers a high level of flexibility as every fire detector can be relocated at any given time. And for configuration and maintenance work, the detectors can be accessed either via the fire control panel or remote access.

To maximally increase safety, every SWING fire detector has a redundant sensor system with two optical and two heat sensors. The integrated **ASA***technology* offers special parameter sets. This allows detector configuration to be optimized to match the expected environmental conditions. **ASA***technology* also interprets the detector signals in real time and adapts the parameter sets dynamically if necessary. As a result, SWING fire detectors are immune to deceptive phenomena like dust, steam or welding fumes and prevent costly false alarms. The detectors are so reliable that Siemens may offer a Genuine Alarm Guarantee for the system. * Offering the highest level of flexibility and reliability, SWING is suitable for use in locations where fire detector wiring is impossible or undesirable for structural or esthetic reasons. Application areas include historic buildings and museums, variable-use industrial buildings and temporary installations for trade shows and exhibitions. Using wireless technology also makes sense in rooms that are occupied almost continuously, such as hotel rooms or offices, and where only a small time window exists for installation and maintenance.

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