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Smart Smoke Detectors for Residential Buildings – Costs, Barriers, and Success Factors

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Abstract

Recent advances in the areas of wireless communication and sensors have led to a decline in prices for smart technologies despite devices being more powerful and reliable now. Nevertheless, the widespread application as well as the functional range of sensor and wireless communication technology in residential buildings is still limited. One application for ubiquitous computing technologies in home environments involves equipping safety systems like smoke detectors, motion detectors, and burglary alarm systems with wireless communication capabilities thus making them a part of the Internet of Things. This paper discusses the role of smart prevention technologies within this emerging domain using the example of smoke detectors. The research discusses costs, barriers for wide-spread use, and success factors of smart smoke detectors and proposes an infrastructure for smart prevention technology. Due to their natural interest in loss prevention, the paper also focuses on the implications of smart smoke detectors for insurance companies as a new application domain for Internet of Things technologies.

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1 Introduction

Recent advances in the areas of wireless communication and sensors have led to a decline in prices for smart technologies despite devices being more powerful and reliable now. Nevertheless, the widespread application of sensor technology in residential buildings is still limited. One application for ubiquitous computing technologies in home environments involves equipping safety systems like gas detectors, smoke detectors and burglary alarm systems with wireless communication capabilities. This paper discusses smoke detectors including their costs, barriers for wide-spread use, and the success factors of enhancing smoke detectors for residential buildings by adding wireless communication capabilities and connecting them to external networks.

Smoke detectors have the potential to reduce the frequency and impact of fire accidents, but still they have a low adoption rate in residential buildings in most countries. For example, in Germany, 600 people die annually due to fires in residential buildings and damage costs of six billion Euros are incurred (GFPA, 2003). However, more countries are requiring the installation of smoke detectors by law and impose fines, if smoke detectors are not installed. This will increase the market penetration and will lead to increased demand for innovative solutions. Nevertheless, state-of-the-art smoke detectors for residential buildings have significant shortcomings. Because the basic version of a smoke detector only emits a local acoustical signal, precious time can pass before the fire is discovered. Smart smoke detectors instead are characterized by three key properties:

- communication amongst smart smoke detectors,
- provisioning of information to external applications, and
- offering of services to be called from external networks.

In case of a fire, smart smoke detectors are able to communicate amongst each other to propagate the alarm within a building and most importantly to someone outside the building via Internet technologies. This is especially useful if the building inhabitants have passed out due to smoke poisoning or if no one is nearby to call the fire department. Besides the basic functionality of propagating alarms, the connection of smoke detectors to the Internet leads to various new application scenarios. Once a smoke detector is connected to the

Internet, it is possible to directly access it from anywhere outside the residence and invoke services offered by the device. This is of interest to insurance companies, who could base their premium models for fire insurances on the installation of smart smoke detectors, or for house owners who want to remotely check if their property is protected. The access to data gathered by smart smoke detectors is also of interest for approaching fire fighters to locate the origin and movement of a fire while they are on their way to the site. In summary, smart smoke detectors control risks of a potential fire in residential buildings by reacting to the fire in real-time and triggering an automatic and early intervention if necessary (Zanetti et al., 2006). The following chapters discuss the possibility to build an infrastructure based on state-of-the art technologies as well as emerging technologies in the area of wireless communication. In addition, the success factors, costs and barriers of a novel infrastructure for smart smoke detectors are discussed. Due to their natural interest in loss prevention, the paper also focuses on the implications of smart smoke detectors for insurance companies.

2 Related Work

Since the utilization of emerging technologies in the area of wireless communication for smoke detectors is a rather specific and application-oriented topic, there are few publications that directly deal with the subject. Nevertheless, there are many technical publications in the area of wireless communication for home automation. For example, Callaway, Gorday et al. (2002) present the different layers of the IEEE 802.15.4 standard and describe how it can be used in home networking applications. Geer (2005) focuses more on the capabilities of the ZigBee technology and discusses market predictions as well as possible application scenarios. Koumpis, Hanna et. al (2005) research the networking of embedded devices to perform industrial control and monitoring. Even though they focus on industrial applications, they provide an overview of wireless standards that can be used for cable replacement in monitoring networks.

Work of interest on the integration of smoke detectors with Internet technologies was conducted by Schmitz and Witschital (2001), who describe possible new services like software downloads and application service providing. They especially stress the point that systems need to be based on open and standardized interfaces to allow for an easy and cost-effective integration of additional components.

The potential of applying early damage detection technologies in the insurance sector is discussed by Zanetti and Fleisch (2006), who describe preventive business processes. They also examine the positioning of insurance companies with respect to the relation between technology and customer. To examine the monetary effect of applying pervasive technologies, Kuehnert et al. (2007) developed a toolset to prove the impact of prevention measures on the extent of damages. From a broader economic perspective, Ramachandran (1998) discusses the domain of fire protection. He examines the economic value of the early detection of fires and provides mathematical models for a cost-benefit analysis.

3 The Infrastructure for Smart Smoke Detectors

State-of-the-art smoke detectors are usually either optical detectors or ionization detectors, which independently indicate a detected fire via an acoustical alarm. But smoke detectors can also be connected with each other to propagate alarms either via cables or using wireless communication modules. As outlined in section 1, a key feature of a smart smoke detector is the communication with other smart devices including further smoke detectors, temperature sensors, cell phones or external networks. For the short-range communication, technologies like Bluetooth or ZigBee are adequate. However, for long-range communication such as sending an alarm message to a cell phone, technologies like UMTS, WiMax or GSM are required. As long-range communication modules are usually more expensive than short-range solutions, it is not cost-effective to equip each smoke detector with long-range communication capabilities. Instead, the infrastructure for smart smoke detectors relies on a wireless communication network, which contains an uplink module to communicate alarms to the outside world. This approach overcomes some of the significant shortcomings of state-of-the-art low-cost smoke detectors. The integration of wireless communication capabilities in smoke detectors frees the infrastructure from the costs and inflexibility associated with cable-based connections between smoke detectors. The approach also makes it easier to upgrade a building with interconnected smoke detectors while providing additional mobility to the system by permitting changes in location of each smoke detector without losing functionality. Another significant shortcoming of standalone smoke detectors is their local acoustic alarm. To overcome this problem, a smart smoke detector is able to communicate with external parties and to inform them about a bursting fire in order to avoid larger damages. To keep the costs of the overall infrastructure low, a hybrid architecture is chosen where one dedicated node in the network acts as a gateway and provides the desired long-range communication uplink. Due to the limited communication range of wireless modules and the characteristics of in-door communication, not all smoke detectors are able to directly communicate with the dedicated base station. Thus in case of a local alarm, the signal needs to be propagated along the network in a multi-hop manner to reach the communication gateway, which then calls the house owner on his cell phone or informs approaching fire fighters about the origin of the fire. Apart from emergency situations the communication gateway can also be used to monitor and control the status of specific smoke detectors remotely. For example, it could constantly send information about the operational reliability of the system to insurance companies, which can then base their fire insurance contracts on the existence and usage of safety technology. An overview of the smart smoke detectors infrastructure is visualized in Figure 1. The figure shows a one-family house, which is equipped with a total of six networked smoke detectors that connect to a communication gateway. A detected fire is propagated along the detectors and the gateway informs the house owner, approaching fire fighters and the insurance company.

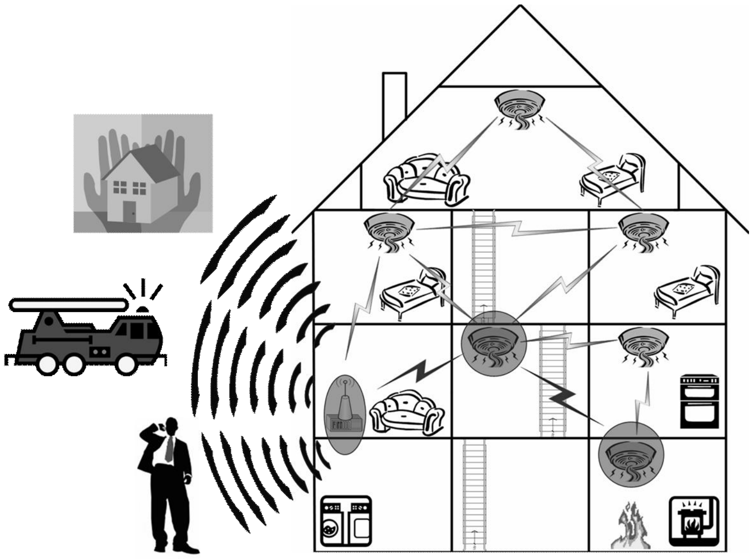

Figure 1: Overview of the Smart Smoke Detectors Infrastructure

4 Success Factors, Costs, and Barriers of Smart Smoke Detectors

Based on the description of an infrastructure for smart smoke detectors in chapter 3, this chapter indicates success factors and requirements for the mass-application of smart smoke detectors, provides a cost estimate for the infrastructure, and discusses why the solution is not widely applied in residential buildings yet.

4.1 Requirements and Success Factors for the Mass-Application of Smart Smoke Detectors

The requirements for an infrastructure for smart smoke detectors need to be examined from different perspectives. On the one hand, end users have requirements concerning the operation phase. On the other hand, there are several technical as well as legal requirements on the infrastructure and the applied technologies.

From an **end user perspective** the following key requirements can be identified:

- **Ease of installation:** End users usually do not have a technical background. Therefore the installation of the infrastructure must be self-explanatory and should not require service by a technician.
- **Low costs:** Even though smart smoke detectors provide additional value compared to state-of-the-art smoke detectors, the customer's willingness to pay is limited. Therefore low costs are crucial for a mass-application of smart smoke detectors.
- **Ease of use:** The technology needs to be very reliable and robust, thus false alarms (type I errors) and absence of alarms in case of fires (type II errors) must be minimal. In addition, there must be minimal or no maintenance efforts.
- **Appealing design:** Since fires and fire prevention are topics people try to crowd out and ignore, the visual impression of fire prevention tech-

nology becomes even more important. Currently, state-of-the-art smoke detectors are unappealing, which contributes to their low distribution.

- **Flexibility:** Flexibility, in terms of rearranging the infrastructure, is important to end users. For example, if a user remodels their flat or moves to a new flat, they should be able to take the equipment with them and easily reinstall it.

- **Privacy:** If smart smoke detectors are connected to the Internet and their data is accessible from the outside, privacy issues will arise. Privacy becomes even more important once the infrastructure contains more than just smoke detectors, like additional sensors that might enable an intrusion into the privacy of end users.

From a **technical perspective**, the infrastructure for smart smoke detectors has to satisfy the following key requirements:

- **Scalability:** As home environments are heterogeneous, the amount of deployed sensor nodes is not predetermined and varies. The technical infrastructure for smart smoke detectors needs to take into account that sensor nodes join and leave the network over time and thus, should be able to cope with increasing amounts of sensor nodes in future home environments.

- **Performance:** For fire prevention technology, the timeliness of alarms is crucial. Therefore, the communication flow between the components of the envisioned infrastructure needs to be fast and fail-proof.

- **Power consumption:** Solving the question of power supply is vital for an infrastructure that is based on wireless communication. While the communication gateway has its own power supply, a smart smoke detector is battery-powered. It is crucial that batteries last for a long timeframe, so the system can operate in a pervasive and unobtrusive way.

- **Integration:** The infrastructure needs to easily and flexibly integrate into an existing system environment. In addition, it also has to be open and based on standards to be extensible towards future applications. Because smoke detectors are just one example of a variety of detection systems, the integration of further systems must be possible by design.

- **Security:** As for all communication systems, the security aspects of the infrastructure must be addressed. This includes protecting individual smoke detectors from external manipulation, as well as securing the data transferred during communication, especially to systems that reside outside the home environment.

From a **legal point of view** the following requirements are important:

- **Legislation:** Politics aim at increasing the coverage of smoke detectors by issuing laws that make their installation mandatory. For example, in Germany, six federal states now mandate the installation of smoke detectors and other states will soon be passing similar laws[1]. In combination with educational advertising by industrial federations, the percentage of residential buildings equipped with smoke detectors has increased from 6% in 2000 to 31% in 2006 (forsa, 2006). As laws regulate that existing households need to recondition smoke detectors during the next years and more states will issue similar laws, the coverage of smoke detectors will increase. The legal initiatives are driven by the understanding that a voluntary installation of smoke detectors leads to an insufficient coverage. In countries like the United States, Australia, England and Norway, the installation of smoke detectors is already required by law. For example, smoke detectors are now present in 93% of residences in the United States, which led to a 40% decrease in deaths caused by fires[2]. This is in sharp contrast to countries like Switzerland, Austria or France where there is no legal regulation around smoke detectors and as a result the coverage is low. However, as laws mandate no controls of the functional efficiency, the installation of smoke detectors is not tracked.

- **Product norm:** Beginning in August 2008, smoke detectors compliant with the harmonized European product norm DIN EN 14604, are the only smoke detectors that can be legally sold in the European Union

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[1] *See http://www.rauchmelder-lebensretter.de/gesetze.0.html.*

[2] *See http://www.wdr.de/tv/service/familie/inhalt/20011219/b_1.phtml.*

(European Union, 2005). Therefore, any newly developed smoke detectors need to be inherently compliant with this norm. The norm also promotes connecting smoke detectors with one another and with communication gateways. For this, additional technical requirements will need to be fulfilled.

4.2 Costs of an Infrastructure for Smart Smoke Detectors

Based on the description of an infrastructure for smart smoke detectors in chapter 3, this section presents two cost calculations and compares the results. The section begins with a cost analysis of a smoke detector infrastructure for residential buildings, which consists of off-the-shelf components. The second calculation applies emerging technologies in the domain of wireless communication to build an alternative infrastructure. The goal is to calculate reference prices for the infrastructure based on the necessary hardware components.

The first cost calculation is based on list prices of the fire prevention specialists Hekatron[3] and CM-PAPP security[4], which can be seen as representative vendors of norm-compliant smoke detectors. The one-family house depicted in Figure 1, which is equipped with a total of six smoke detectors that are connected via radio, is used as a reference object. In the examined infrastructure, every smoke detector "HSD IV LongLife" is equipped with a "Duo-Line" or "Duo-Line Plus" module for radio communication. To ensure a reliable communication, it is necessary to apply the "Duo-Line Plus" version on the first and second floor of our reference building because it has a repeater capability to improve signal strength. Lastly, the network is connected via the gateway module "Radio Interface Duo-Line Plus" to the "Monitoring Station CM7008" that submits the alarm to a cell phone. Table 1 shows the cost calculation for a state-of-the-art smoke detectors infrastructure that is able to report an alarm to a given external cell phone.

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[3] See http://www.hekatron.de/media/downloads/datei/537_gesamtkatalog_rauchwarnmelder_07.pdf.

[4] See *http://www.cm-security.com/pdfs/katalog/de/CM_PAPP_Katalog_2005_07_21_Internet.pdf*.

Table 1: Cost Calculation for a State-of-the-Art Infrastructure

	Category	Unit Price	Quantity	Total Price
HSD IV LongLife	smoke detector	€ 29.95	6	€ 179.70
Duo-Line	radio communication	€ 49.95	4	€ 199.80
Duo-Line Plus	radio repeater	€ 69.95	2	€ 139.90
Radio Interface Duo-Line Plus	radio interface	€ 159.90	1	€ 159.90
Monitoring Station CM7008	communication gateway	€ 350.00	1	€ 350.00
				€ 1,029.30

For the cost calculation presented in Table 1, compatible components offered by two companies that specialize in safety engineering for residential buildings were combined to match the sketch of a smart smoke detectors infrastructure. Even though the choice of components represents the cheapest possible configuration, the total price for such an infrastructure is still more than € 1,000. At this price level, a mass-application of smart smoke detectors for securing residential buildings is unlikely. Therefore, in the following sections, I propose an infrastructure for smart smoke detectors based on new and emerging technologies like wireless communication networks. To be able to validate the profitability of the new approach and compare it to the previous cost calculation, I calculate the corresponding hardware costs for an alternative infrastructure.

An analysis of the cost structure of the presented state-of-the-art solution shows that the communication components of the infrastructure are the largest expense factor. An approach to reduce the costs is to deploy low-cost emerging technologies in the area of wireless communication, without altering the basic smoke detectors. In addition, the proposed new approach makes use of existing infrastructure to cut costs. The selection of an appropriate technology to achieve the outlined goal is based on semi-structured interviews with several vendors of wireless communication technologies. The focus of the interviews was on the functionalities and costs of the respective technologies. It is important to note that for a prototype implementation of the infrastructure, the available technologies need to be further examined and compared in more detail. For the purpose of this paper, the first reference price calculated based on data from technology vendors is sufficient.

The information gathered from both the conducted interviews and additional desk research lead to the decision to apply ZigBee nodes and connect those to the existing IT infrastructure. ZigBee-compliant nodes are based on the IEEE 802.15.4 standard (IEEE, 2006) and designed for low-battery consumption, ad-hoc networking and reliable multi-hop communication. Use cases describing smoke detectors are included with other existing ZigBee use cases in the areas of industrial control, embedded sensing, medical data collection, and home automation. Therefore, ZigBee-compliant nodes offer the capabilities required in the given infrastructure and can be used to calculate a reference price.

Besides the wireless communication, the infrastructure also requires some uplink functionality. For this purpose, a ZigBee-to-Ethernet bridge can be used to connect the system to an existing router and use its Internet connection as an uplink for the alarm notification on a cell phone or for further communication purposes. While this setup relies on existing infrastructure, it can be argued that Internet connections are widely available in home environments and therefore the approach helps to further cut costs. Nevertheless, it is also possible to replace the ZigBee-to-Ethernet bridge with a ZigBee-to-Cellular bridge for a direct communication, which is independent of an existing infrastructure, but imposes higher costs.

The cost calculation in Table 2 uses list prices for ZigBee nodes from MaxStream[5], a provider of wireless device networking solutions. The company was chosen because it is one out of four manufacturers that sell products certified by the ZigBee alliance and also because they offer products that match well with the requirements of the depicted infrastructure. Therefore, the products can be used for the calculation of a reference price, keeping in mind that

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[5] *See http://www.maxstream.net/products/catalog_web.pdf.*

the calculated price is an initial approximation to compare state-of-the-art solutions with emerging technologies.

Table 2: Cost Calculation for a Novel Infrastructure

	Category	Unit Price	Quantity	Total Price
HSD IV LongLife	smoke detector	€ 29.95	6	€ 179.70
XBee ZigBee OEM RF Module	radio communication	€ 14.00	6	€ 84.00
ConnectPort X8, Ethernet	communication gateway	€ 93.00	1	€ 93.00
				€ 356.70

The calculation in Table 2 considers list prices for end users, while prices can further decrease with volume discounts. In addition, as Table 2 shows, the smoke detectors account for half of the price of the overall infrastructure. As mentioned before, legal directives concerning the installation of smoke detectors will lead to an increased demand, which will lower the prices for basic smoke detectors. Moreover, ABI Research (2006) estimates that the market for ZigBee nodes will grow from 92,000 nodes shipped and revenue of $ 552,000 in 2005 to 124.60 million nodes shipped and revenue of $ 174.44 million in 2011. This should lead to a decrease in prices for ZigBee communication modules. In summary, the application of the emerging ZigBee technology and its integration with the existing IT infrastructure leads to a decline in costs from € 1,029.30 to € 356.70, which equates to cost savings of 65 %.

The conducted cost analysis compared only hardware costs for a state-of-the-art implementation and a new infrastructure proposal. While this is reasonable as hardware costs are the main cost factor, further costs will need to be considered as well. For example, the communication between the network and external parties generates additional communication costs, especially for connections to cell phones. In addition, costs for system installation, maintenance and battery replacement also need to be considered. As the novel infrastructure combines several components, it is also necessary to consider sunk costs associated with the initial development of integration software.

4.3 Barriers fort he Market-Penetration of Smart Smoke Detectors

This section investigates why smart smoke detectors are not widely applied in residential buildings even though their benefits are obvious. Based on the cost estimation for a state-of-the-art infrastructure, the high costs of such an infrastructure can be identified as one key hindering factor. But to understand the reasons for the low adoption rate of smart smoke detectors, we need to start our considerations one step earlier because the market-penetration of ordinary smoke detectors is surprisingly low as well. According to a study on the adoption of smoke detectors in German private households (Forschungsgruppe g/d/p, 2005), the level of familiarity with smoke detectors is 98%. Nevertheless, smoke detectors are deployed in only 31% of the residential buildings and home owners and large families with children are more likely to install smoke detectors.

Even though most people are familiar with smoke detectors, their distribution is low in countries that do not regulate their deployment by law. This is largely caused by misconceptions about the danger of fires. Most people are not aware of the fact that 95% of all people who die in fires are killed by smoke poisoning from inhalation of smoke, not the actual flames. In addition, 70% of these deaths happen at night, because the sense of smell is inactive while sleeping[6]. The lack of knowledge about those facts leads to the misconception that most fires are discovered at an early stage by the increasing heat and that there is enough time to leave the house. This wrong assessment of the dangers of fires is paired with a psychological crowding-out effect. The act of concerning oneself with a life-threatening situation and actively purchasing a smoke detector is prevented by the rejection of unpleasant topics. To some extent smoke detectors are also seen as aesthetically unappealing, which is especially the case in luxury flats or architectural monuments. Another reason for the low adoption rate of smoke detectors is the high rate of false alarms. In the United Kingdom in 2005, about a third of all fire-related incidents were false alarms caused by smoke detectors (Department for Communities and Local Government, 2005, p. 61). The high rate of false alarms also results in an increased number of installed but inactive smoke detectors because people

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[6] *See http://www.rauchmelder-lebensretter.de/10.0.html.*

disable devices after annoying false alarms. In addition, many devices are inactive because batteries were removed and used elsewhere like in a remote control. The short lifetime of batteries as well as the limited functionality of state-of-the-art smoke detectors can be seen as further adoption barriers.

Market-penetration of smart smoke detectors is mainly delayed by the high costs of wireless communication modules. The emergence of new technologies for wireless communication in home environments has the potential to decrease the costs of an infrastructure for smart smoke detectors. While section 4.2 showed that at current prices, the infrastructure costs can be lowered already, with the predicted drop in prices for wireless communication, costs will be cut further.

A retarding factor for the application of emerging technologies like ZigBee is the reliability and availability of the network, which are key requirements in the domain of safety technology. As wireless communication networks are still less reliable than cable-based solutions, the market-penetration is slowed down until the technologies are mature enough for a broad application in safety-critical environments. The discussion of network reliability also leads to questions of accountability in case of network failures at the time of a disaster.

5 Value Proposition of Smart Smoke Detectors

This section discusses the value proposition of the presented infrastructure for smart smoke detectors from the perspective of end users and insurers as well as from a technology point of view.

5.1 End User Perspective

For end users the most obvious effects of installing smoke detection technology are increased safety, a decreased risk of fire, and a lower expected monetary loss. If the technology is provided by insurance companies or if they offer more attractive insurance premiums for installed smoke detectors, the technology installation has an additional monetary effect for end users. As the system is equipped with communication capabilities, it also becomes possible to automate certain tasks like battery and function tests to increase the availability of the system while freeing the user from this burden. As technologies advance, end users will soon be able to interact with the system using cell phones or any ZigBee-enabled end device. For example, Telecom Italia is currently testing a SIM card with an integrated ZigBee gateway named Z-SIM (Turolla, 2007). This will inherently provide access to a deployed ZigBee-based infrastructure as cell phones are a commodity. The concept allows using the cell phone as a user interface to control the system or as a dashboard to receive for example a battery replacement notification via text message. In addition, the utilization of open communication standards enables an easy extension of the existing system. This means that every new device only needs to be equipped with a ZigBee module to integrate with existing devices and the communication gateway. From a cost perspective, the initial investment in the communication gateway is spread over more and more integrated devices as the system grows.

5.2 Technology Perspective

The wireless communication in state-of-the-art smoke detectors is usually based on proprietary communication protocols. Therefore, a key contribution of the infrastructure proposal is the application of open communication standards to allow for the integration of additional systems and sensor nodes. In this respect, the smoke detectors infrastructure can be seen as a foundation for the future integration of various wireless home automation systems within residential buildings. This overcomes the shortcomings of available legacy solutions and allows for an open and extensible integration infrastructure. For example, the infrastructure can seamlessly integrate further detectors like gas detectors, water detectors or burglary alarm systems. The only prerequisite is that every new technology that is integrated with the existing infrastructure supports the common ZigBee communication standard.

An example of device-to-device communication in the case of smoke detectors is the following: when a smoke detector recognizes an emerging fire, it informs nearby detectors, which propagate the alarm. In addition, it sends signals to the sprinkler system as well as the smoke and heat venting system to extinguish the fire. Another example could be the integration of networks between adjacent houses. If both networks use the same communication standards, it would be possible to propagate the alarm from a node at the verge of a building to the close-by neighboring house. This way it would be possible to establish a neighborhood-spanning safety system where several buildings might even use a common communication gateway. Finally, the bidirectional communication between smart smoke detectors and the Internet allows for incoming messages as well. For example, house owners could be warned about an upcoming tornado by the civil protection agency, which would trigger a dedicated acoustic alarm on the smoke detectors inside each residence.

5.3 Insurance Perspective

The application of ubiquitous computing technology, like smart smoke detectors in residential buildings, is of special interest for insurance companies. The application of more effective early detection technology has the potential to reduce fire insurance claims. This will cause the total loss expenses for insurers to drop because of a decreased frequency of severe burnings and a lower amount of damages per case. The emergence of smart home safety technologies also has strategic potential for insurers, who could use smart smoke detectors as a new link to their customers. Besides the positive effect on the combined ratio due to reduced losses, the introduction of information technology in the relation between insurers and their customers makes the "product" insurance appear more tangible and gives it a "look-and-feel". This allows for a modular design of insurances, which for example consist of a household insurance, smoke detectors, water detectors, and a burglary alarm system. The different detection systems could be introduced step by step during the renewal of the original insurance contract. As a consequence, insurers might use the technology to move from selling insurance contracts to selling "safety", which means that they decrease the probability of damage from an accident while insuring the remaining risk. Applying a more holistic insurance concept using smart smoke detectors has the potential to lead to increased customer loyalty and improves the image of the insurance company, which can position itself as a prevention insurer. The application of technology also offers the chance that customers loose the subjective impression, that they never receive any return service for the paid insurance premiums. In addition, the technology leads to additional contact points, which are the base for cross- and up-selling processes. Insurance companies can also realize first-mover advantages, if they integrate smart technologies in their customer relations and therefore differentiate their product portfolio from competitors (Zanetti et al., 2006).

An open question for insurance companies is how to distribute the technology amongst customers. Active distribution using the existing channels of insurance agents is possible, although it is unclear whether insurance companies are interested in directly providing high-tech solutions to their customers. To hide the underlying complexity of the technology from both customers and insurance agents, third-party technology providers could mediate between both parties. A more detailed discussion of distribution options can be found in (Kuehnert et al., 2007). Finally, the applied technology can act like nerve endings for insurance companies by providing data from customers that was not available before. For example, an insurer would be able to tell whether the infrastructure for smart smoke detectors is active at a given moment or which detectors are broken. If an insurer states in the fire insurance contract that claims are unjustified in case of gross carelessness, and it is assumed that powerless smoke detectors are a gross carelessness, the insurer will not have to pay for damages if a fire occurs because the system was not working properly. In general, data coming from smart home environments has the potential to enable more fine-grained and risk-based ratings of insurance contracts. An insurance company could base the rates of premiums on the application of smoke detectors. If customers are expected to buy the technology themselves, the insurer could offer reductions in premiums as compensation even though this might not be of interest to insurers. On the other hand, demanding higher premiums from customers, who do not apply the technology, poses risks, that these customers will decide to change insurers and go with a competitor instead.

6 Conclusions and Future Work

This paper provides an introduction into the vision of smart smoke detectors. It describes what the underlying infrastructure looks like and gives examples of use cases that can be realized based on smoke detectors that are wirelessly connected and integrated with the Internet. The work shows that this vision can be realized to a limited extent by state-of-the-art technologies, but at high costs. In contrast, emerging technologies like ZigBee create options to implement the same scenarios at lower costs and enable a variety of new scenarios. This paper outlines the value proposition of smart smoke detectors from several perspectives in addition to discussing in detail the barriers and requirements. Based on the discussion of various perspectives on smart smoke detectors, I conclude that the concept is very promising in terms of delivering high functionality at low prices, although there are still some barriers to overcome and requirements to meet.

As this work showed, there is a trend towards a multinational legal requirement mandating the use of smoke detectors. Therefore, a solution based on smart smoke detectors could be one alternative for an emerging mass market. To better understand the requirements and expectations of house owners, a survey amongst end users is planned. In analyzing the gathered data, reasons for the low market penetration of conventional smoke detectors, success factors for innovative smoke detection systems and the willingness to pay for innovative solutions can be discovered. This will help understanding which functionalities are requested by end users at which price to successfully manufacture and sell a smart smoke detector solution to consumers. Another open research field is the positioning of insurance companies. While the benefits of smart smoke detectors are obvious, it is still unclear to which extent insurance companies should be involved in the distribution and operation of the technology. In addition, it has not yet been examined which data coming from home environments is of interest to insurance companies. Therefore, expert interviews with insurers are necessary to explain the technological concepts to them and to better understand their interests. It also needs to be explored how data coming from smart home environments allows for a more fine-grained and risk-based rating of insurance contracts.

In addition, the business case for smart smoke detectors needs to be built. This paper showed how emerging technologies can lower the price of a smart smoke detectors infrastructure. A next step involves calculating the lowest price for the infrastructure. For example, the smoke detectors used for the calculation in section 4.2 can be replaced by cheaper models to cut costs. Then, the costs need to be compared with the willingness to pay of end users as well as the willingness to subsidize of insurers. This in turn gives insights on the existing monetary gap for a mass-application and should be combined with predictions about the cost development for used components in order to analyze how the gap will develop over time. Finally, after the technology is examined in more detail and the business potential is verified, a prototype implementation for a smart smoke detectors infrastructure becomes possible. As most components are readily available at fair prices and most of the work concerns integration tasks, a prototype could then be built at reasonable costs.

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