Application of the Cognitive Radio Concept for M2M Communications: Practical Considerations

Adrian Kliks

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Abstract This review paper aims at providing a description of the application possibilities of the cognitive radio concept for machine-to-machine communications in the business facilities or intelligent buildings steered automatically by means of dedicated management systems. It starts with an overview of the current solutions of wireless communications between devices (e.g., sensors, cameras, computers, pumps, heating modules etc.), followed by a more detailed description of selected system configurations and requirements. Moreover, the idea of intelligent radio will be presented, and finally the proposals of the application of this concept in building management systems will be evaluated. In the whole analysis, practical limitations and real system requirements will be taken into account.

Keywords Cognitive radio · Machine-to-machine communication · Building management systems · Intelligent building · Intelligent company · Telemetry

1 Introduction

The rapid and continuous growth of the amount of data to be transferred through networks is one of the main motivations for the application of new communication systems all over the world [1, 2]. It has been observed during the last decade, how the so-called 2G wireless systems, such as GSM or IS-95 [3, 4], have been replaced by 3.xG, just to mention UMTS, HSPA and LTE [5–8], and currently by 4G solutions, i.e., LTE-A, or broadly IMT-A. The same improvement can be noticed in the field of broadcasting (such as digital television or radio, e.g., DVB or DRM) [9, 10]. One cannot omit the widely used Wi-Fi networks [11, 12], as well as the WiMAX technology [13]. Also the wired communication systems have

A. Kliks (✉)

Chair of Wireless Communications, Poznan University of Technology, Polanka 3, 60-965 Poznań,
Poland
e-mail: akliks@et.put.poznan.pl

been significantly improved during the last decade, having in mind traditional dial-up modems, xDSL solutions, and now the IPv6 technology applied to the optical networks delivered directly to home or office. One can also state that in parallel to the extreme increase of the data traffic generated by humans, it is envisaged that in the upcoming years the amount of data exchanged between devices, or better machines, will increase dramatically (such a communication scheme is known as Machine-to-machine communications, denoted also in form of M2M) [14]. In [19], it is even stated that 'operators believe M2M is just one of a number of future growth opportunities'. This observation brought many researchers to the concept of the Internet-of-Things [20], concerned with allowing effective and autonomous communication between machines. Though wired connectivity between machines is obviously desirable, it is often not possible in real implementation due to technical restrictions, of which the lack of network infrastructure or a high number of network nodes are the crucial ones. A simple example is a terrain that belongs to a company located in a suburban area, equipped with a dedicated measurement system, in which high numbers of sensing nodes communicate between each other. In such a case, the installation of wired connections between the sensors is neither cost-effective, nor simple. This is the reason why wireless communications gains a lot of attention. It can be observed that in most of the systems installed on company terrain or in so-called intelligent buildings the possibility of the application of wireless entities is nowadays one of the natural options. Such an observation, however, leads to some conclusions. First, the electromagnetic compatibility issues between tens or hundreds of communicating nodes originating from various systems deployed in buildings seems to play one of the most crucial roles in the near future. Second, wireless communication between the sensors themselves assumes the application of battery-supplied elements, thus energy-efficient solutions will be preferred. Moreover, the possibility of adaptive and intelligent management of the installed wireless systems implies new possibilities for a better, more effective data exchange. Following this analysis, one can notice that cognitive radio networks (please see [21]), in which the transmit parameters of the system are not pre-defined and can be adapted freely depending on the current situation, seems to be a good candidate for the application in machine-to-machine communications (M2M). Although the pure concept of cognitive radio is not applicable now mainly due to the lack of local and international regulations in that field, some of the solutions proposed in rich scientific literature originally devoted to cognitive radio could be easily used in practice for M2M communications in companies and intelligent buildings. This paper provides an analysis of the possibilities of the application of the cognitive radio concept in practical scenarios. The remainder of the paper is organized as follows. First, M2M communication techniques currently used in various systems installed in companies, factories or buildings are described. Then, the idea of cognitive radio is presented, and the use-cases for cognitive radio are provided. The paper is concluded at the end.

2 M2M Communications: Current Solutions and Requirements

Machine-to-machine communications [14–17, 19] have been considered, or even already applied, in many branches of local and global economy. The main idea behind the information exchange between devices, i.e., autonomous entities not controlled by humans, is to allow the systems to adapt their parameters according to the current situation in an area or vicinity. Such adaptation and reconfiguration ability will mimic artificial intelligence of such a system, making it more affordable in everyday use. It is obvious that proper behavior

of systems strongly depends on the amount and the reliability of data exchanged between nodes. Various forecasts show that in the nearest future, a tremendous and immense increase in the traffic generated by machines will be observed all over the world. Such observations are the basis of the concept of the so-called Internet-of-Things [18], as opposite to or an extension of the current global network used mainly for transferring data between humans. However, M2M communications is nowadays most often applied in systems installed in a very limited area, such as companies or buildings. Although most of the already installed systems have been built using wired connections between nodes, the advantages of wireless communications seem to supersede the traditional solutions. However, manufacturers have usually decided to propose well-established and grounded wireless technologies for data exchange, such as GSM, Wi-Fi, IEEE 802.15-like family (e.g. ZigBee [22, 23] or Bluetooth [24]) or other short range solutions. The trends in the automatic system development strongly suggest the need for new solutions in that area. The great amount of information to be exchanged, the increasing popularity of intelligent automatic systems in every area of our living, new functionalities devoted to the existing solutions and the envisaged features of the cities of tomorrow (intelligent lights, road signs, buildings, etc.) guarantee in some sense the application of advanced techniques also for M2M communications. In that light, the very active investigation undertaken withing the Weightless SIG [25] on the new M2M wireless transmission standard seems to be one of the technical enablers, which can be implemented in that area. It is worth mentioning that the standard, also called Zero-G, allows the operation in unused TV bands, known as TV white spaces [26]. Let us now briefly analyze some of the various types of the systems in which automatic, autonomous and bidirectional information exchange between network nodes (devices) is carried out in the background of such systems.

2.1 Ad-hoc, Wireless Sensor Networks

One can easily mention the so-called ad-hoc networks, in which randomly deployed sensors or, in general, network nodes can adaptively organize the structure of a network in such a way that some of the predefined targets will be reached [27, 28]. In such a case, the removal of some network elements or the addition of new ones results in automatic network reorganization. Moisture sensors scattered randomly over a wide area, such as a garden or golf-field, for the purpose of measuring ground humidity and making decisions about starting automatic irrigation is an excellent example of the practical application of an ad-hoc network. Another example is a wireless network used for gas detection, e.g., in hard-accessed areas, such as mines. The amount of data that has to be exchanged between nodes is quite small, however, the main challenge is to make the wireless communication as energy-efficient as possible. It should be noticed that the damage of one sensor (node of the network) does not stop the proper functionality of the network. The ability of the “self-recovery” of network topology makes such a solution particularly useful in practical applications where the stability of network operability is required. Another practical application (selected arbitrarily from a vast set) of an ad-hoc wireless network is proposed by, e.g., Honeywell, and it is called the OneWireless Network Honeywell [29], where Wi-Fi standards are considered for data exchange, but also the dedicated wireless networking technology standard ISA 100.11a developed by the International Society of Automation (ISA), devoted to automation application [30, 31]. However, one can imagine a case in which sensors of different types are placed in the same physical area, thus the problem of mutual interference immediately arises. Moreover, one of the directions for future research will be to integrate various types of sensors in one device and to control them in an

intelligent way, depending on current needs. Moreover, the amount and type of data exchanged between the nodes in such an ad-hoc network may change in time and may be steered by a management center. Such a strategy requires radical changes in the current approach to the solutions of that kind.

2.2 Security Systems

Another representatives of the existing wireless system, in which particular elements communicate autonomously with each other, are access control and supervision systems broadly applied for security purposes in bussines facilities, universities, offices etc. [32–34]. The main difference between these systems and ad-hoc networks described before is the static nature of the network topology. In such a system, specialized sensors, being the end-elements of the network, are installed in locations specially selected for that purpose and they forward the values of measured parameters to a fusion center. The center collects the broadcasted messages, analyzes them and autonomously makes appropriate decisions. After that, the decisions are delivered to entities, such as barriers, air curtains or sprinkler controllers, making them perform dedicated actions. The sensors have to provide cyclic reports of the measured values and adapt their behavior to the guidelines indicated and received from a network controller. Nowadays, particular network elements are obviously connected using wires or fibers, however, due to the convenience of wireless communication and its lower installation costs, more and more wireless solutions can be applied in such security and supervision systems. In the considered case, the main problem is the reliability, stability and security of the wireless connections. Nevertheless, one can forecast that in the nearest future, such systems will be equipped with more sophisticated functionalities, i.e., the system could be even more adaptable and change its behavior depending on current situation. One example will be to change the way of transferring the video signal. In the normal mode, wireless cameras will transmit a signal of an assumed quality using wireless technology X, whereas in the special case, additional cameras will be activated for creating a 3D or multi-view signal, which will also result in the change of the wireless technology. Such an approach assumes the ability of cognition in such systems.

2.3 Intelligent Road-traffic Management

It can be observed that in the previous examples, the network nodes are static, i.e., the nodes cannot independently change their physical position. Contrarily to that, in vehicle-to-vehicle or vehicle-to-infrastructure systems, most of the nodes (e.g., cars, vehicles) can move (in some sense) autonomously, and only a relatively small set of nodes (such us lamps, traffic lights, bridges etc.) are static. However, the rationale of such a solution is the nodes' ability for a fast and reliable data exchange. Cars can communicate with each other, informing about traffic jams, car crashes, weather conditions, current speed, etc. They can also negotiate with infrastructure elements. If necessary, the controlling nodes can request the exchange of specific data and the adaptation of selected transceivers. One can notice that due to the huge number of cars and infrastructure elements, the main problems of such a solution are the effective transmission protocol and electro-compatibility issues. The standardization process for such systems is under way (e.g., the work done on the development of IEEE 802.11p standard [35], or in general withing Intelligent Transportation Systems concept, such as Wireless Access in Vehicular Environments WAVE [36]), and the first practical tests are carried out all over the world.

An interesting extension of such a system is the concept of smart cities, which includes intelligent road signs (not only traffic lights) that adapt themselves based on the data collected from the network, as well as information gathered by sensors (e.g., humidity sensors embedded in the road surface, day light sensors etc.). Beside the roads, also the electricity networks, road-lanterns, as well as buildings themselves should be intelligent, one should cooperate and adapt to the changing environmental situation. Some practical implementations of the smart city concept can be found in [37].

2.4 Telemetry

Let us have a look at telemetry, a great solution to the problem of periodic collection of data from thousands or even tens of thousands of devices located in private premises, such as electricity meters. Automatic or remotely triggered measurements and reporting is a cost-effective alternative to the current solutions in which workers collect all reports manually. The implementation of telemetry in practice requires, however, an intelligent design of the whole network (topology, protocols, security solutions, etc.) and a precise definition of the crucial reporting parameters. It should be able to modify the measurement strategies depending on, e.g., the payment tariff selected by a user. Moreover, such meters could also be integrated with other systems installed within the house, and thus they could react to the changing sets of the parameters of those systems. An arbitrary selected practical system devoted to telemetry is proposed in [38].

2.5 Building Management Systems

Currently, offices and new business facilities are predominantly built in such a way that a variety of systems are installed in them. This includes the already mentioned systems for access-control, security and supervision, but also for ventilation combined with fire protection, light, window and blinds control, domestic sewage management and garden irrigation, just to mention the most popular ones. Usually, most of these systems are integrated, what requires their proper management. Such a role is played by the so-called building management system (BMS) [39–41], a system being, in some sense, the heart of a building, and developed for the management of all other deployed systems. Clearly, with the advent of new intelligent systems applied more and more often in buildings, a further development of the BMS is inevitable and indisputable. In the further part of this paper the concept of policy-based BMS will be presented.

3 Cognitive Radio

The goal of this section is to describe the basics of cognitive radio [47]. In its first part, the cognitive cycle, also known in robotics and automatics, will be presented. Then, the problem of the high underutilization of frequency resources will be analyzed, with particular attention paid to the potential reuse of the so-called TV white-spaces. Finally, the idea of a policy-based radio will be presented as a candidate for the application in BMS.

3.1 The Cognition Cycle

The concept of cognitive abilities of systems or devices has been known for many years in the area of robotics and automatics, and with some restrictions, it can be treated as the basis

of artificial intelligence. The basic cognitive cycle contains of five mutually connected phases, as it is illustrated in Fig. 1.

The first phase assumes the observation and recognition time, during which the device or the whole system collects information about the surrounding environment at a given time stamp. Next, based on the gathered data and on previous experience, the device or the system controller can make a decision either to modify its behavior or to continue the current activities unchanged. After that, the realization of the agreed decision is enforced, and the results are analyzed, thus the device starts the fourth phase devoted to learning. Finally, based on the gained experience from the past, various parameters can be adapted, beginning at the same moment next round of cognitive cycle. Obviously, the phases are mutually connected, i.e., based on the feedback obtained in the learning phase or on the signals coming from the outside (e.g., authentication center, regulator, administrator etc.), the device can immediately go to the appropriate state, e.g., finishing transmission. In terms of wireless communications, the concept of cognitive cycle has been proposed by J. Mitola (e.g. [47]).

3.2 Spectrum Scarcity

Although the ability for the cognition of system parameters has been known for decades, it has recently been also proposed for telecommunications, and in particular, for its wireless part. Similarly to robotics, cognitive radio is sometimes described as a radio equipped with artificial intelligence. It could then, e.g., sense the environment (observe), make decisions on the transmit-receive parameters (decide), start stop transmission (act), analyze the achieved performance and connect it with the assigned transmit-receive parameter set (learn) and finally, potentially modify the current behavior (adapt). Besides providing more intelligence to wireless phones and the network itself, the rationale for such a rapid development of wireless communication in that area is the scarcity of the available frequency resources. Due to the static form of spectrum management and licensing, the spectrum appears to be underutilized. In other words, a certain amount of the frequency spectrum is assigned to a specific technology (called the primary system) and cannot be reused by other systems (secondary systems) even if in the current location, the licensed one is not present. Various studies and real measurement campaigns carried out in various countries on different continents, have proved that the average frequency occupancy in the urban areas reaches at maximum 20–25 % [42–46]. The situation is even worse in rural areas, where this value can be even lower than 10 %. Such an observation leads to the conclusion that opportunistic management of the spectrum could be the solution to that problem, and it is the subject to intensive research and standardization activities all over

Fig. 1 The cognitive cycle

the world. It is considered that this approach will be particularly suitable for machine-to-machine communications. As mentioned in the previous section, it is foreseen that the number of cooperating machines (including sensors, actuators, controllers, devices etc.) will increase significantly in the upcoming years. Thus, let us notice that such a situation will also result in a high increase of the traffic generated by these devices. This will emphasize the problem of the limited abilities of the current technologies used for data transmission and the issue of inefficient spectrum management. In that light, the application of the opportunistic access concept will be the solution to those problems.

3.3 Digital Switch-off

Intelligent and dynamic spectrum management is a good idea for solving the problem of high spectrum underutilization. However, in order for it to be applied in practice, some more detailed proposals have to be identified. One of them is the cognitive use of the so-called television white-spaces for M2M communications. It has been agreed in most countries that analogue television would be switched off by 2016 and new digital television will be broadcasted. Since digital television is much more efficient in terms of the utilized frequency resources, many of the currently occupied television channels will be released. The vacant frequency gaps found in the TV band at a given location and time are called TV white spaces (TVWS). Following the recent recommendations of the leading regulation and standardization bodies (Federal Communications Commission from USA or Ofcom from UK, but also CEPT, ETSI and IEEE), the TV band, i.e., 470 to 862 MHz, will be probably assigned for cognitive application. In other words, broadcasters will be the licensed users that possess the priority for transmission in a given band [48–50]. However, if locally a given frequency band is free of TV transmission, or TV receivers cannot be protected (as it could be imagined inside factories), particular TV channels can be designated for M2M communications. It is worth mentioning that such a frequency band is particularly suitable for transmission, since the lower the frequency, the lower the transmit power required to achieve the same distance and the better wall penetration. In other words, observing the current direction of regulations, TVWS seems to be very attractive as the potential means of data exchange between machines.

3.4 Policy-based Cognitive Radio

Finally, let us briefly analyze how the practical implementation of the cognitive radio concept, or more specifically, of the opportunistic access to the frequency band (especially TVWS) can take into account various limitations and restrictions imposed by system providers, technology used or national legal regulations. Let us analyze the following example. Currently, the electromagnetic compatibility of the devices allowed for use in a given country is based on the communication technology applied (i.e. assumed in-band and out-of-band power emission, assumed maximum power etc.), elements of the printed circuit board, and known communication systems working in adjacent frequency bands. The introduction of the cognitive radio will completely redefine the certification process, since the devices will adapt their transmission parameters (including the transmission band used). That and other analogous observations have led the researchers to the idea of a policy-based cognitive radio. In the neXt Generation (XG) radio [51], it is assumed that the future devices shall be manufactured in such a way that they will be able to apply any of the current and future restrictions defined in appropriately prepared policies. In other words, the manufacturers, national regulators, system administrators or other authorization

bodies can define a new set of rules in terms of machine understandable policies, and the devices will be obliged to follow them. Such an approach can be easily extended from individual devices (machines) to whole networks that will modify their behavior depending on the policies currently delivered to the system from an authentication center. Moreover, intelligent systems—such as the systems used nowadays in modern buildings—will be allowed to modify their behavior autonomously only when such modification complies with the assigned set of rules. One can easily observe that such a concept could be applied in a variety of existing solutions, such as BMS.

3.5 Spectrum Sensing and Other Limitations

One of the main technological drawbacks of the cognitive radio is the necessity of reliable spectrum sensing [52] or fast connection to the database containing the records with the definition of the vacant frequency bands and permissions for their usage by unlicensed users. As in the case of the cellular network, the reliability of the existing techniques is not satisfactory, since the time required to get stable results is too long. However, in the case of an industrial application for M2M communication, this could be much easier. First, the presence of the database in a building controlled by BMS is obvious, and second, the time issue is not as crucial, so reliable techniques for the detection of free spectrum bands can be found.

4 Application Proposals

Based on the analysis provided in the previous section, we will now discuss the direction of potential application of the cognitive radio concept in practical realizations. As a background for our analysis, we first consider the forecasts showing the very significant growth of the traffic generated by devices in M2M communication. Moreover, it is important to reduce the amount of energy consumed by the systems, since it would reduce the costs and make the systems "greener". Thus, let us first concentrate on the TV white spaces. As it was mentioned before, the considered band for cognitive transmission is mainly from 470 to 792 MHz. Such low frequencies are particularly suitable for low-power emission, since the range of the transmit signal for a given transmit power P_{Tx} decreases reciprocally in proportion to the frequency. So the higher the frequency, the lower the potential range of the signal. It also means that for a given distance, less power can be delivered to the antenna load when lower frequencies are used for transmission. Furthermore, the attenuation of walls and other obstacles is lower as the frequencies decrease.

4.1 Proposal 1: Delivering Wireless Communication for the Company

Taking this observation into account, one can state that the usage of TV white spaces for cognitive communications, especially for M2M transmission, where the problem of efficient energy utilization is of the highest importance, is an excellent idea. Obviously, the problem of disturbing the primary systems (licensed systems) by the secondary (unlicensed) transmission appears immediately. However, looking at the practical applications of cognitive wireless links, these will be mostly limited to the area of one company building or company premises. The transmit power of M2M transceivers should be adapted in such a way that the communication range would not cross the company boundaries. Moreover, such a requirement will be more easily fulfilled if the non-adjacent TV channels

are selected for wireless communications, which should be feasible in most countries and locations. This is illustrated in Fig. 2. One can notice two digital television base stations (DTT) transmitting on channels 41 and 45. The unlicensed (cognitive) transceiver is utilizing the same TV channels from 41 to 45. In the case when the channel 41 or 45 is used, the requirement of not inducing harmful interference to the primary (licensed) user is guaranteed by the proper adaptation of the transmit power. Whereas when the channels 42 up to 44 are utilized, i.e., the communication is realized in the adjacent and non-adjacent channel, the proper definition of both the transmit power and transmit mask acts as a guarantee of not distorting the primary signal. Based on the guidelines defined by FCC and Ofcom e.g. [48, 49, 53], the shape of the transmit mask and the maximum transmit power can be calculated in a straightforward manner. Finally, let us observe that any of the existing standards, adapted to the new frequency range, can be used for data exchange between the network nodes used within a company.

4.2 Proposal 2: M2M Transmission Over TVWS

In the above example, the general communications within a firm is proposed, i.e., an internal wireless network could be implemented in that way, and since lower frequencies are used, lower transmit power will be used making the wireless communications “greener”, and reducing the OPEX of the company. However, such an application can be easily adapted to strict M2M communications, where energy efficiency plays a crucial role. Following the recent ITU recommendation for path loss modeling [54] in short-range outdoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz, let us illustrate the exemplary path loss reduction by shifting the transmit frequency from 1GHz to 500 or 600MHz. In this example, the line-of-sight has been assumed, and the height of the transmit and receive antennas has been set to 40 and 1.5 m. (Note that the calculation of the more accurate values requires a proper adaptation of the path loss model to the environment where the company is located). One can observe that in the shown range of interest for most companies, the path loss reduction is equal to around 6 dB when shifting from 1 to 0.5 GHz, and up to 12 dB when moving from 2.5 GHz. This allows us to approximate how much energy can be saved by changing the frequency range from GSM or Wi-Fi band to vacant TV channels Fig. 3.

Fig. 2 Exemplary scheme of CR based M2M transmission

In Fig. 4, one can observe the considered company premises with a specialist system installed there. The nodes are communicating via e.g. GSM or Wi-Fi and are deployed in the form of an ad-hoc network. By shifting from the frequency 900 MHz, 1.8 GHz or even 2.4 GHz down to, e.g., 500 MHz, one can reduce the total power consumed for data transmission. For battery supplied sensors (devices in general), it straightforwardly means a longer working time, and thus another cost reduction.

In the next example, two coexisting systems are deployed in the same building (Fig. 5), where the nodes of the first system are black, while the nodes of the second system are white. Taking into account the amount of the released vacant spectrum in the TV band, it can be imagined that these two systems could use neighboring channels for data exchange. The selection of the currently used frequency band would depend on various factors, such as the number of nodes in the network, or the required protection ratio defined for that system.

4.3 Proposal 3: Back-up or Hot-reserve Link via TVWS

Moreover, high attention has recently been gained by products which can autonomously select one of the two offered technologies for wireless communications. Two typical scenarios are usually considered. In the first one, the devices (network nodes) of the specialist system transmit data using, e.g., GSM network. In the case of network congestion or any other troubles with connection stability and reliability, an alternative link is automatically started, using, e.g., UMTS. Similar solutions have been proposed for Wi-Fi connections, where the nominal link is realized by means of the utilization of the 2.4 GHz frequency band, whereas the 5GHz band is used as the hot/cold reserve link. In the second scenario, both frequency bands are occupied. One can easily imagine that the presence of the vacant bands and the possibility of their utilization opens new perspectives to system designers. As mentioned before, lower frequencies seem to be a very attractive alternative to the open 5 GHz band. One can also notice that the probability of network congestion in such a solution would be very limited, i.e., when the system tries to select the TV channel number, e.g., 43, and this one is already occupied, it can try to use the next one. Such a functionality, however, requires some kind of central or distributed management and the ability of adaptation in the real time. This issue will be addressed in the next sections.

Fig. 3 Path loss for various transmit frequencies according to ITU-R model [54]

Fig. 4 Industry building with one cognitive ad-hoc network

Fig. 5 Industry building with two cognitive ad-hoc networks

4.4 Proposal 4: Usage of TVWS for Data Collecting Over Large Area

The next proposal concentrates on the problem of automatic data collection over a very large geographical area, usually tackled in the research field of smart metering. The digital switch off from the analogue to digital television results in the presence of relatively large number of vacant channels, and these channels could be used for sending data from the smart meters to the collecting center. Let us imagine the situation illustrated in Fig. 6, where an exemplary network topology has been suggested. The short-range connections

could be realized by means of cognitive connection. smart meters, installed in people's houses or flats will monitor the frequency spectrum and define the vacant TV channels in given localizations. Next, this channel will be used for delivering the measurements to a local collecting center. Finally, the local connecting center will transmit the bursts of the gathered measurements to a central collecting center, and finally, the central center will use radio-link (and regular connections) for data transmission. However, if the company wishes to use TVWS also for radio-link connections, it also seems possible. Such a case is shown in Fig. 7. One can observe three TV stations covering wide geographical areas. In each of such areas, specific TV channel is occupied and excluded from TVWS usage. In the proposed network topology, the main fusion centers localized on building roofs (see Fig. 6 for comparison) transmit the packages of collected measurements to the steering center of a separate region (such as a village, housing, estate, or simply a group of buildings) using one of the vacant TV channels. Finally, these steering centers communicate either with the neighboring steering centers or directly with the company office. Such a solution is feasible, since the deployment of TV towers is performed once for a long period of time and the TV channel assignment is usually unchanged.

4.5 Proposal 5: BMS Using Policy-based Cognitive Radio

Finally, let us analyze the aforementioned problem of the management of the deployed wireless systems which possess the functionality of selecting the transmit channel in an adaptive (cognitive) way. The functioning of the installed system has to be controlled by a building/area administrator who should have knowledge of the parameters currently used by the considered system. That administrator has to possess relevant privileges and tools for defining and delivering new behavior rules of the systems in the building. It should be possible to define that, e.g., system X cannot/is obliged to use certain frequencies in a given range. It should be able to indicate that in the case of any conflicts when accessing the spectrum, priority will be given to system Z. Moreover, since opportunistic access to the

Fig. 6 Local measurements realized by means of TVWS connection

Fig. 7 Data collection over large area using TVWS

spectrum assumes a dynamic usage of the resources, it can be foreseen that any changes of local or national regulations might destroy the normal functioning of the systems. Thus, it should be possible to define and apply the requirements and limitations coming from regulators or other official accreditation bodies. Current building management systems are very well developed and control a great variety of systems, defining, e.g., the time relations between them, privileges, rights, etc. Thus, a natural extension of the present functionality is to add to the BMS the possibility of controlling the frequency bands used for transmission, mutual dependencies between the systems, and the main functionalities (e.g., if TVWS is used as a cold or hot reserve link, or maybe the main link). Policy-based cognitive radio (Fig. 8), i.e., radio controlled by a set of policies, is the immediate solution. Let us analyze the following example. The BMS controls the systems deployed in an intelligent skyscraper, including, e.g., fire, admission control, security, ventilation and light-control systems. In the case of normal work, all systems have an exactly identified set of parameters defining their behavior in details. However, admission control utilizes the solution that is based on Wi-Fi connections and for some reasons, the number of the observed collisions with other open systems functioning in the building (such as a newly installed wireless monitoring system)

Fig. 8 Policy-based cognitive BMS

may make the behavior of the system unstable. Thus, the BMS server could analyze the situation and try to assign vacant TV channels in the given location. Assuming that the problems with Wi-Fi connections are temporary (e.g., due to a big event organized in the building), the default configuration could be easily restored.

5 Conclusions

This paper presents an the analysis of the potential application of the cognitive radio concept in the automatic industry. It has been proved that there are many practical scenarios that could be taken into account for the application of cognitive radio systems, from signal delivery to the company premises, to the connection of the existing nodes, to telemetry and BMS. One can easily draw the conclusion that the problem of energy-efficient transmission between machines in factories or intelligent building may offer an interesting alternative to the current solutions.

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Adrian Kliks received his M.Sc. and PhD degree in Telecommunication from Poznań University of Technology in 2005 and 2011, respectively. Since 2005 he was employed at the Institute of Electronics and Telecommunications, and since 2007 at the Chair of Wireless Communication in the Faculty of Electronics and Telecommunication. He was hired first as the senior researcher (2007–2009), assistant (2009–2011) and starting from October 2011 is employed in the position of assistant professor. His research interests cover the wide spectrum of wireless communications. In particular he is interested in multicarrier (both orthogonal and non-orthogonal) systems, in the area of cognitive radios, small-cells and in radio-planning. Since 2007 to 2008 he was the chairman of the PhD Self-Government at the PUT. He was the originator of organization and the co-chairmen of the organizing committee at the First International Interdisciplinary Conference of Young Scientists InterTECH 2008. He was involved in preparation of national and international conferences, such as Euro-

pean Wireless 2012 conference (April 2012, Poznan, Poland), as well as workshops like CRAFT workshop at ISWCS 2013 and MACNET workshop at PIMRC2013. Currently he acts as one of the organizers of the workshop at IEEE WCNC 2014 (Istanbul, Turkey) on Interference and Design Issues for Future Heterogeneous Networks. For 9 years dr Adrian Kliks is a member of IEEE, and from 2012 he reached the status of IEEE Senior Member. He was/is involved in industrial and international projects (like ICT-URANUS, NoE NEWCOM++, NEWCOM#, COGEU, ACROPOLIS, COST Action IC-0902, COST-Terra), where he also acts/acted as the task leader. Within these projects he was awarded with international exchange grants (realized in University of Pisa and CTTC in Barcelona). He acts/acted also as a reviewer for various journals (e.g., IEEE Transactions on Wireless Communications, Wireless Personal Communications) and conference papers (e.g. IEEE Globecom, IEEE PIMRC, IEEE ICC, IEEE VTC). He organized various special sessions at international conferences (like CrownCom, WSA, Eusipco). Currently, he participates actively in working groups established for definition of IEEE 1900.x standards on cognitive radio. He is also the leading guest editor of the Special Issue on future heterogeneous networks that will be published at EURASIP Journal on Wireless Communications and Networking. From 2014 he acts as the Membership Development/Web Visibility Chair at the IEEE ComSoc Europe Middle East Africa (EMEA) region. From 25 November 2014 he is a member of Radio Communications Committee and Research Group on Software Defined and Virtualized Wireless Access.