Quality Of Service and MObility driven cognitive radio Systems

White Paper

Business Opportunities and Scenarios for Cognitive Radio Systems

Abstract

The European Commission project QoSMOS specifies and develops a cognitive radio system which will allow opportunistic use of radio spectrum for mobile users as well as providing managed Quality of Service (QoS). If opportunistic wireless access is to be a real alternative to current licence-based technology it must be able to provide at least as good a user experience. Some of the most interesting business opportunities are the access to the wireless market for new entrants and well as benefits for current wireless operators. Some examples are easier access to new markets, capacity enhancements, spectrum sharing, spectrum trading, cost and performance gains in existing networks and new services.

If a cognitive radio system is to be attractive for actors in the wireless industry, it has to provide significant benefits. Consequently, the QoSMOS project has defined several criteria to find feasible deployment scenarios for cognitive radio systems. These criteria address both technical and commercial factors. The resulting promising scenarios are cognitive femtocells, cellular extension in whitespaces (including rural broadband) and cognitive ad-hoc networks. All of these could provide a benefit, either for new entrants, or for existing wireless operators and fixed broadband operators. Some initial business case definitions have been set up.

Spectrum trading is an important tool to increase overall spectrum utilization and to open up opportunities for businesses to get access to desired spectrum. An ecosystem for spectrum trading consisting of spectrum traders, spectrum brokers, spectrum databases and a spectrum regulator has been defined. In addition, a wireless sensor network may be implemented to provide more detailed information about the real-time spectrum status. Fair trading is dependent on well-defined trading metrics which are quantifiable measures of the performance of the trading market. Recommended high levels metrics are market viability, channel quality, spectrum utilization and social welfare.

This white paper explains the business environment in which cognitive radio may exist and benefit in the future.

Introduction

There is a growing regulatory trend to allow for licence-exempt or opportunistic use of underutilised spectrum in some selected licensed bands. The aim is that currently congested spectrum does not become more congested, and that underutilised spectrum is better exploited. An opportunistic user has to act as a *Cognitive Radio* (CR) as it is required to avoid interference towards incumbent users and cooperate fairly with other opportunistic users.

The EC-funded project QoSMOS [1] has as its main objective to research, specify and develop the techniques necessary in a cognitive radio system to allow opportunistic use of radio spectrum for mobile users as well as providing managed QoS. To fulfil this main objective, QoSMOS is addressing the full range of technical issues: transceiver designs, efficient use of aggregated and fragmented spectrum, environment modelling and sensing, protocols for signalling and communications, cognitive manager, and security aspects. To set the scene for the technical research, a use-case and economic analysis is done, which is the topic for this white paper.

Spectrum that can be available for opportunistic access is commonly referred to as 'whitespace' (WS). One issue with WS is the need for fairness among other opportunistic users. It may be difficult for a commercial system to provide high QoS guarantees using whitespaces alone. This is because the load contributed by opportunistic users is unpredictable, whereas the provision of even a minimal service level imposes a lower limit on the available bandwidth required. In some scenarios whitespaces may be used in addition to some licensed spectrum, to provide congestion relief and added functionality, whereas other systems may be able to function purely on the whitespaces alone. The current interest for opportunistic access is very much focussed on the UHF TV broadcast band (470 – 790 MHz). Regulators in the UK and USA are already defining rules for opportunistic access in this band [2][3][4][5]. In addition, military bands are subject to investigations and future release including a wide range of frequencies.

Identifying scenarios at an early stage in system development is important as this can keep further development aligned, working with a common goal in mind. The QoSMOS project has identified scenarios and use cases for opportunistic access using a systematic and business oriented approach, and these are presented below.

Business Opportunities for Cognitive Radio Systems

This section highlights the most interesting business opportunities for cognitive radio.

Easier access to new markets

Cognitive radio is expected to offer business opportunities for different players, including wireless operators, fixed operators and new entrants.

One of the main difficulties wireless operators wanting to enter new markets face is to get access to adequate spectrum. Often, there are no spectrum licences available and a new operator has to either wait until a suitable spectrum licence becomes available or get access to spectrum through one of the current spectrum owners. The latter case can involve cooperation or spectrum leasing agreements with current spectrum owners, or even buying one of the spectrum owning companies. All these alternatives represent time-consuming processes and significant costs.

By using cognitive radio and use spectrum opportunistically, the start-up time and initial costs will be significantly reduced. In the start-up phase, with few customers, the traffic in the network will be relatively low and opportunistic spectrum will be sufficient for offering the wireless service with the required quality. As the number of subscribers increases the new operator might want to get access to additional licensed spectrum to ensure that it will be able to maintain the QoS service quality as the traffic increases. To handle special events creating peak traffic, for example, sport or concerts, capacity can be extended by adding opportunistic spectrum to the licensed spectrum.

Opportunities for new entrants

Many companies offer services that can potentially be enhanced or extended by combining them with a wireless service, but has been prevented from doing so due to the high investments required to get access to spectrum. Examples of such companies are fixed broadband operators that want to extend their offering with a mobile service and companies from the computer industry that want to extend their services to include wireless access. Computer industry companies includes software companies like Microsoft, Internet service companies like Google and chip and equipment manufacturers like Dell and Intel. These companies have all shown interest for using TVWS spectrum for wireless communication.

Capacity enhancements

An existing wireless operator having an infrastructure in an area can use opportunistic spectrum to increase the capacity of its network. In order to do this the operator will have to add cognitive radio capabilities to its network and some or all of its users must have terminals with the necessary cognitive radio functionalities. However, this can be a much cheaper solution for the operator than deploying more base stations or buying more spectrum (if that is possible at all). This is especially interesting for serving capacity demands in a limited time frame, such as for special events.

Spectrum sharing

Cognitive radio can be used as an enabling technology for spectrum sharing between operators. Cognitive radios have the ability to get information about how the spectrum is used in their environments and adapt their transmissions to minimize the disturbance to other radios. Hence, they are very well suited for this application.

The gain of spectrum sharing is larger if the traffic peaks occur at different times in the different operators' networks. An example of a good match of operators could be a fixed WiMAX operator serving the business market and a mobile operator serving the consumer market. The WiMAX operator would have its traffic peak during daytime while the mobile operator would have its traffic peak in the evening.

Spectrum trading

Spectrum trading is a business opportunity for wireless operators to get revenues from their spectrum at times when they do not need all of it themselves. Spectrum trading is also an opportunity for new actors to enter the wireless communication ecosystem, such as spectrum brokers and pure spectrum owners. This opportunity is discussed separately in the latter part of this white paper.

Cost and performance gains in own network

Wireless operators can improve their own spectrum efficiency by using cognitive radio technology. Cognitive radio systems are able to adapt their operation according to given criteria, and can for example be used for optimizing transmissions, automating operational tasks and optimizing network tuning. Self-organizing network functionality, as defined by 3GPP [6], can be seen as an early implementation of this.

New services

Different properties of cognitive radio can be used for offering new services. One example is to exploit cognitive radios' ability to know their environment and know their users' needs to offer environment- and context-aware type of services. Such services can be seen as an extension of location-based services, which are already offered as a service by some operators.

IDENTIFYING ATTRACTIVE SCENARIOS

For a Cognitive Radio System (CRS) to be attractive for most players in the wireless industry, it has to provide a significant benefit compared to what is possible with today's and tomorrow's mainstream wireless technology. Mainstream technology like 3GPP's LTE, with the evolution towards LTE-Advanced, and Wi-Fi has a great momentum in the market, and will also provide significant improvements in performance as well as cost in the years to come. It is also worth mentioning that CR approaches are considered to be included in the future releases of LTE-Advanced.

Deploying CRS for a particular scenario should provide a significant potential benefit for the actors.

The QoSMOS project has defined three main criteria in order to select feasible deployment scenarios for a CRS providing both managed QoS and high mobility [7][8].

- Benefit from CRS technology: the CRS solution should be able to provide a significantly better performance than existing (conventional) systems.
- Benefit for actors: deploying CRS for a particular scenario should provide a significant potential benefit for the actors. This criterion addresses the commercial side of the CRS, and the selected scenarios must be likely to provide a better business case than conventional systems.
- Managed QoS and mobility: the scenario should cover a range of QoS and/or mobility demands. A scenario's QoS requirements depend on the traffic classes that it will serve and how demanding these traffic classes are.

Further, the following criteria should be used for targeting the most interesting and promising scenarios for business case studies.

- Market Potential: the scenario should have a large market potential, e.g. with respect to the number of user terminals or expected revenue for the service.
- Best Technological Solution: no other solution should appear as a better (with respect to performance, cost, environmental benefits, and so on) solution for the given scenario.

- Technical Feasibility: it must be probable that this system can be implemented with current state-of-the-art technology or beyond state-of-the-art technology achievable within a reasonable time frame.
- Economic Feasibility: it must be probable that within a period of 3-10 years it will be possible to produce equipment and services to a cost that match the users' willingness to pay. The scenario must offer profitability for all major actors in its ecosystem.
- Regulatory Feasibility: if the solution requires regulatory changes in order to be deployed, the changes should be such that it is reasonable to expect that they can be realized within a reasonable time frame.
- Ecosystem Feasibility: the ecosystem may consist of customers, partners, suppliers, competitors and local and national authorities. If the scenario imposes great changes in the ecosystem (for example, roles which disappear), it will be much harder to get acceptance for the solution in the industry.
- Benefits for the society: local or national authorities may be willing to support deployment of a system if the social benefits it represents are large. Political support can also make it much easier to get acceptance for regulatory changes.

SCENARIOS FOR COGNITIVE RADIO SYSTEMS

Based on the above criteria, the QoSMOS project has developed and defined three promising scenarios for CRS representing both technical and commercial feasibility and attractiveness.

As more frequencies are available than in conventional deployments, network coverage or capacity can be increased, improving user experience.

"Cognitive femtocell" scenario

This scenario could also be considered as a CRS hotspot. The cognitive femtocell describes small base-stations, typically deployed to distribute domestic broadband in the home or to provide internet access in public hotspots. The cognitive femtocell extends on the conventional idea of femtocells in cellular networks but also on Wi-Fi type deployments. Cognitive femtocells are likely to be an evolution of current femtocell technology.

Benefits

The cognitive femtocell should offer better interference control than current cellular (for example, 3G/LTE) femtocell technologies so that coverage and/or capacity can be improved upon. Also, as more frequencies are available than in conventional femtocell/Wi-Fi deployments network coverage can be increased, improving user experience.

A star topology will be used consisting of base-stations and multiple end user devices. The number of end users per base station is likely to be low, in the range of one to ten. The base stations will have gateway functionality as well as access control. The end-user devices are typically smart phones, tablets and laptops, but other devices such as voice-only handsets and sensors are also possible. The services required by this scenario include a full range from voice telephony to high bandwidth multimedia.

Examples

There are many possible examples of a cognitive femtocell deployment; three are shown here. The first, shown in figure 1, is an extension of a typical Wi-Fi deployment where individual base-stations distribute internet connectivity through a private home. The cognitive femtocell will be able to offer better interference management and therefore better capacity and/or coverage. In figure 2, the second example is a public hotspot where several femtocells provide coverage for a particular location. Access at these hotspots might be available to the public or limited on a commercial basis. The third example in figure 3 is inside-to-outside coverage. This is where indoor femtocells provide coverage to users in the streets outside buildings.

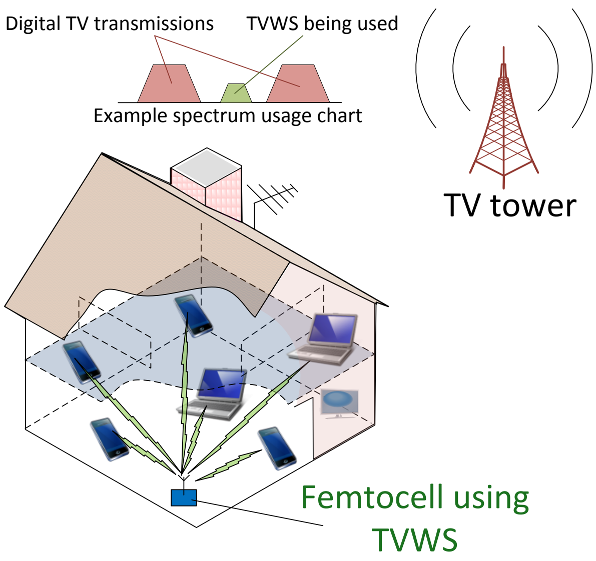

Figure 1 Cognitive femtocell used as Wi-Fi extension

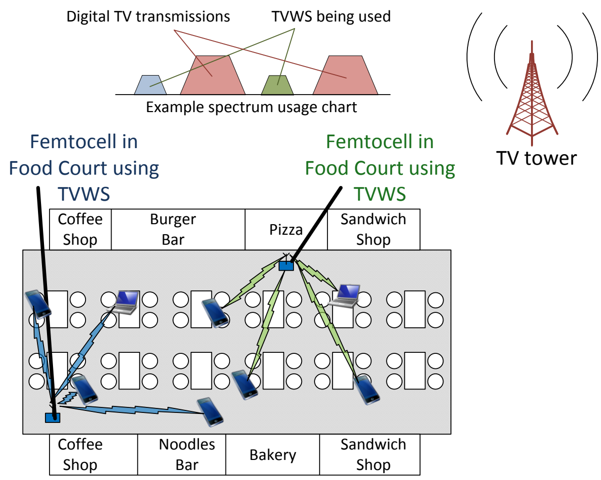

Figure 2 Cognitive femtocells used for public hotspot

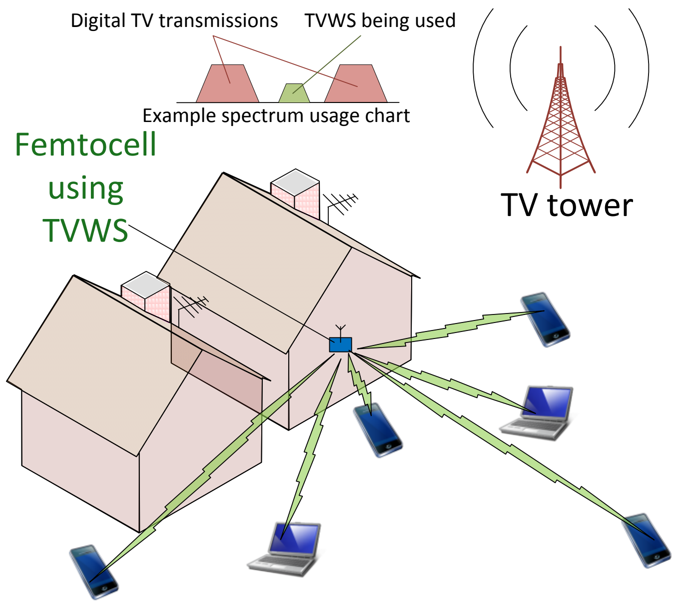

Figure 3 Cognitive femtocell used to extend indoor coverage to outdoor

Business case for the "Cognitive femtocell" scenario

A possible business case for this scenario assumes that fixed network operator which will use cognitive femtocells to extend its operation to be able to offer a mobile broadband service to its customers. The operator is assumed to be one of the leading fixed network operators in the studied considered area. It has a large market share in fixed broadband based on DSL (Digital Subscriber Line, broadband over copper lines), HFC (Hybrid Fibre Coax, broadband over cable TV networks) or FTTH (Fibre to the home) solutions. It has an extensive cable, transport and switching infrastructure and an existing organisation for sales, marketing, technology and operation.

The operator will use TVWS (470-790 MHz) in a cognitive way to extend its business to also include mobile voice and broadband services. Using this low frequency band is a key enabler due to its beneficial properties in through-wall propagation. The operator will offer cognitive femtocells to its customers, which will then be installed in people's homes and in offices. It is assumed that the range of the femtocells will extend outside the walls of the houses and buildings and that they are open for access to users passing by. The operator uses its fixed broadband network to provide backhaul capacity for the cognitive femtocells. It is assumed that the femtocells will be LTE femtocells, meaning that LTE terminals will be able to connect (clearly there are no LTE terminals that support this frequency band now, but it is assumed that such support will come in some years).

With this scheme, the fixed operator will have a mobile network covering its subscribers' homes and offices and their immediate surroundings. Since it is well known that a large part of the mobile usage happens when people are at home or at their office, a large part of the mobile traffic of the operator's subscribers will go in this network. To provide full mobile coverage to its customers, the fixed operator must have a roaming or MVNO (Mobile Virtual Network Operator) agreement with one or more of the existing mobile operators.

The main advantage of this solution for the fixed operator is that it can extend its business towards mobile services without acquiring spectrum licences and without having to build outdoor sites or to get access to other operators' sites. It can utilize its own infrastructure and the existing customer relations.

“Cellular extension in whitespace” scenario

This scenario describes a mobile operator whose network will use whitespace spectrum in addition to its own licensed spectrum in order to improve the coverage and/or capacity of their network as shown in figure 4. This additional bandwidth can allow the operator to improve load balancing, link quality and offer more flexible services.

In areas where multiple mobile operators using cellular extension in whitespace exist, the whitespace spectrum will be shared. The sharing will be controlled by spectrum management functions and a spectrum database.

Benefits

Extra whitespace spectrum can provide peak-hour traffic offloading. The frequency of whitespace spectrum will determine whether it is more suitable to increase the coverage or the capacity of a cell. For example, low frequencies tend to propagate further for a given transmit power making them better suited to increase cell coverage.

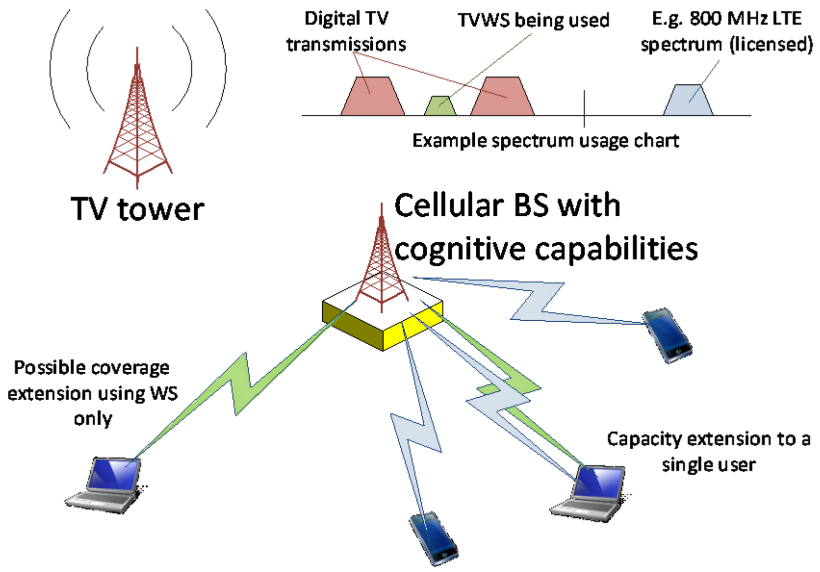

Figure 4 Cellular extension in whitespace applied on LTE

Examples

Rural broadband is a special case of the cellular extension in whitespace scenario. This involves the provision of internet connectivity to homes in rural locations through a base-station using whitespaces (see figure 5). This scenario could be the most economically viable way for a service provider to provide a broadband service to locations that have either no existing fixed-line broadband connection or the fixed-line connection can only offer very low broadband speeds. Typically 2Mb/s is considered as the lowest rate currently required.

The service will act as the home broadband connection for end users so there will be high QoS requirements to allow for the range of services typically demanded. However, the mobility requirement is removed for this scenario as the end users will be homes. The house is likely to have an outside antenna. This can reduce propagation loss which can offer benefits such as lower power consumption, increased range and the potential to use cheaper, less sensitive, equipment.

The base-station connects to the homes in a point-to-multipoint topology with links that are typically in the range of 1-10km. Given the need to propagate several kilometres, low frequency whitespaces such as TV whitespaces would be favourable.

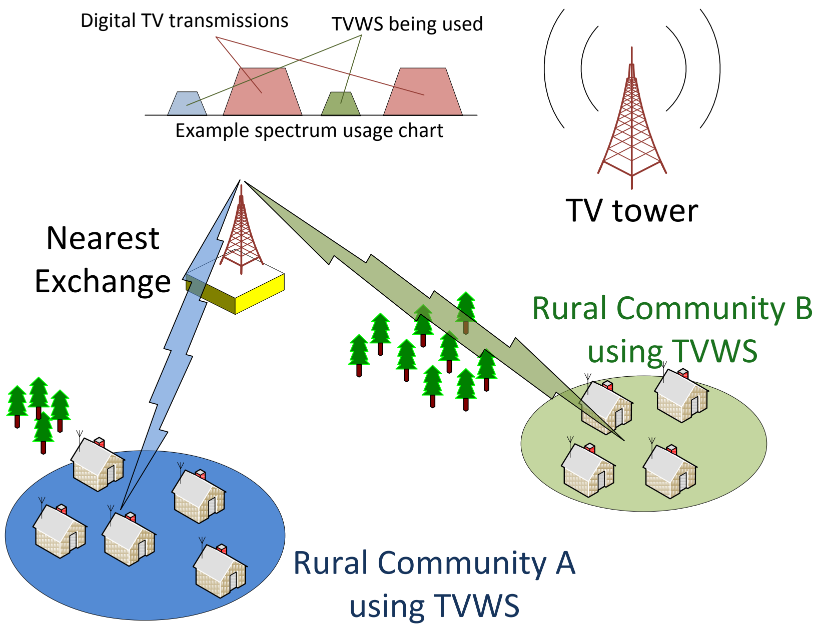

Figure 5 Rural broadband using TV whitespaces

Business case for the "Cellular extension in whitespace" scenario

A possible business case for the "Cellular extension in whitespace" is that a cellular operator with an existing infrastructure use TV whitespace spectrum in a cognitive way to enhance its mobile broadband offer. The enhancement will mainly be in the form of additional capacity for serving more customers and/or offer higher capacity to each user. For the cellular operator, this can be seen as an alternative to waiting for some of these frequencies to be freed from TV use to mobile broadband ("Digital Dividend 2" – DD2) and acquiring spectrum there via spectrum auctions. When (and if) a DD2 spectrum auction comes, the operator can try to get licensed spectrum to secure that its network has the necessary capacity to serve its customers.

Since the TV broadcast spectrum usage is relatively static, a cognitive radio solution based on geo-location and spectrum databases is a good and economical solution. This is also the solution proposed by FCC [2][3] and Ofcom [4][5] in the TV white spaces. This means that the user terminal and/or the network must have geo-location capabilities and it might be necessary for the operator to pay a fee to the database operator. Also, this business case must take into account that cognitive functionality is required both in the base stations and the user terminals.

The physical site infrastructure costs (masts, towers, cabinets, antennas, power supplies) are very significant in any mobile operator business case. The business case of a new mobile operator will be dominated by these costs. Since the goal of this business case is to investigate the economical potentials of using opportunistic TV white space spectrum, an operator having an existing infrastructure should be assumed. The revenues will then be in the form of additional revenues, that is:

- Increased number of customers because of more capacity available

- Additional ARPU (Average Revenue Per User) because some customers shift to "premium" products
- Reduced churn because of improved customer satisfaction

Business case for the "rural broadband" scenario

The rural broadband business case is applied to the situation where a service provider cannot already provide fast enough broadband to customers using existing fixed-line infrastructure. The reason for the low fixed-line speeds is often due to the line length between a customer and the nearest exchange. Upgrading the fixed line infrastructure (for example, installing fibre-to-the-building or fibre-to-the-node) is often not economically viable when groups of customers are small and far from an exchange.

TV whitespace spectrum is suitable for reaching these sorts of customers as the frequencies should be able to propagate for several kilometres (distance is dependent on many factors including maximum allowable transmit power and terrain). This means that base-stations can be deployed on existing infrastructure that the network operator owns or has access to. The likelihood of a DD2 could offer advantages or disadvantages to a rural broadband solution. If the rules of any DD2 allow for fixed broadband deployments then this gives the option for some TV spectrum to be bought, thus allowing for better guarantees for a minimum level of service. If DD2 does occur then this can reduce the amount of remaining TV whitespace. This could create challenges in areas where the amount of TV whitespace availability is relatively low.

Having the base-station and Customer Premises Equipment (CPE) outdoors means that geo-location with spectrum databases is a suitable way solution for accessing whitespaces, and having the customers' antennas outside and at roof-top level improves the wireless link considerably.

The business benefits for rural broadband can include:

- Reduced costs - Compared to the alternative option of improving the fixed line infrastructure.
- Increased revenue – More customers can now receive a broadband service.
- Reduced customer churn on customer phone lines – A service provider typically provides broadband along with phone lines. Customers now have extra incentive to keep their phone line with their service provider.
- Subsidies – Some governments/councils may subsidise rural broadband developments as a way to reduce the growing digital divide between rural and urban areas.

"Cognitive ad-hoc network" scenario

Ad hoc networks are typically limited in both time and space. The cognitive ad-hoc network will use whitespaces to connect terminals. As this network uses whitespaces, it should have an internet connection in order to meet regulatory requirements. Without such a connection the regulatory requirements may be to have much stricter spectrum sensing capabilities.

Benefits

Whitespace frequencies can be chosen for particular requirements, such as coverage. Also, the amount of bandwidth can be adjusted to meet the current system demand. This is an advantage over systems with licensed spectrum where the amount of spectrum available may be limited during peak times and underutilised at off-peak times.

The terminals in these networks are often end-user devices which include additional functionality such as ad-hoc network routing and relaying. Other types of terminals include server nodes. Star and mesh topologies are possible configurations. In the star topology there is likely to be a server node with routing functionality. The server node could contain a resource allocation function which would control all traffic flows in the network, even those which do not go via the server node. In a mesh topology there may be no central controller which would therefore require that each station contains a spectrum manager.

Examples

An example of a cognitive ad-hoc network is that of an emergency situation (see figure 6). At the location of an emergency situation, users from several emergency services, such as police, paramedics, fire fighters, may require the ability to communicate with each other; and also with their rescue coordination centres. These systems would have to be quick to deploy and highly reliable.

Machine-to-machine (M2M) communications are also a form of ad-hoc network. M2M communications has a very wide scope of use cases itself. Early suggestions for M2M in whitespaces include running a large scale network of connected devices (for example, smart meter service) and sensor networks (this also has a wide scope: spectrum sensing systems, security sensor networks and healthcare sensor networks).

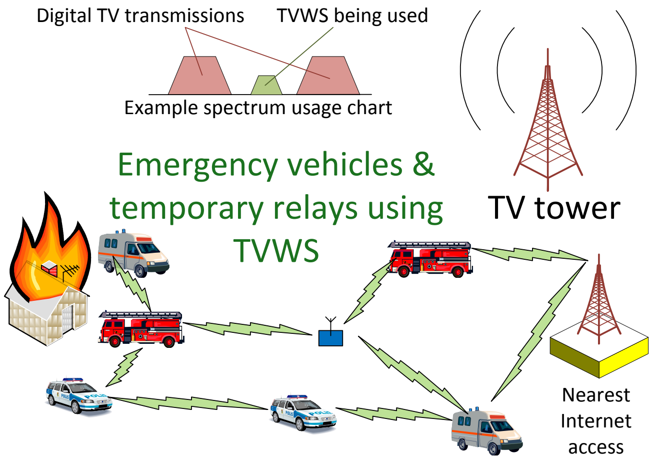

Figure 6 An emergency cognitive ad-hoc network

Business case for the ad-hoc scenario

The ad-hoc network for emergency situations has a clear benefit for social welfare, which should greatly help the business case. To justify the business case for emergency scenarios it is essential to gain accurate requirements about the connection reliability. This will also give an indication of the maximum single-hop distance that can be allowed in this deployment.

For machine-to-machine communications there is already an interest in smart meters. TVWS could be a suitable way to connect smart meters in homes to the wide area network due to its favourable propagation characteristics.

In short the potential applications for the ad-hoc scenario are many, with each possible application having its own set of requirements. The feasibility of each application has to be done on an individual basis. These assessments are the subject of ongoing work within the project.

SPECTRUM TRADING OPPORTUNITIES

Spectrum trading is an important tool to increase overall spectrum utilization and to open up opportunities for businesses to get access to desired spectrum. Regulatory rules for spectrum trading have been implemented in some countries for some spectrum bands, for instance in the UK [9] and US [10][11][12]. At the same time, systems and architectures for cognitive radio technologies are being developed that are able to dynamically use spectrum bands with higher flexibility including functionalities such as dynamic bandwidth, spectrum bands concatenation, sensing, channel switching and cognition. However, the current spectrum trading regimes usually require long times to execute a trade, hence limiting the flexibility at short time scales. Therefore, the concept of spectrum micro-trading is a concept to enable trading of spectrum at the micro scale in three dimensions; on the micro-spatial, micro-temporal and micro-frequency scale.

> ***Spectrum trading is an important tool to increase overall spectrum utilization and to open up opportunities for businesses to get access to desired spectrum.***

Ecosystem for Spectrum Trading

The ecosystem and roles identified to be involved in a spectrum micro-trading market are illustrated in Figure 7 and described in the following.

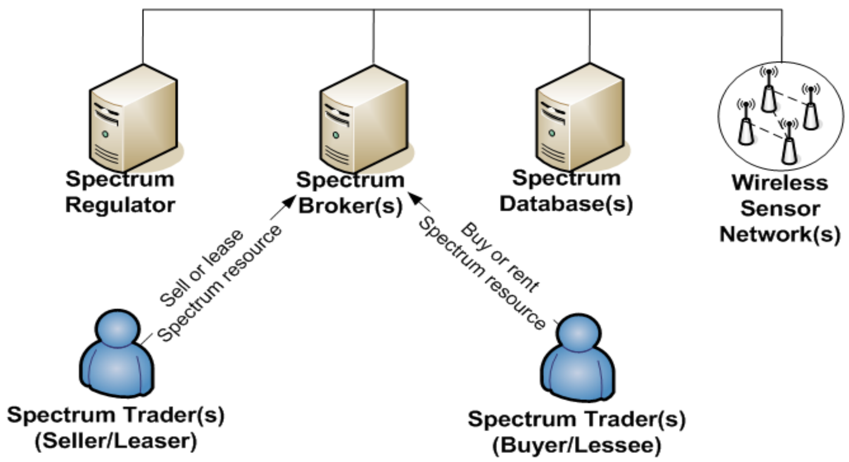

Figure 7 Roles in the ecosystem

A *Spectrum Trader* can be a seller, buyer, leaser or lessee. The trader can even take on more of these roles and also speculate in the market. The following actors may take on the role as a spectrum trader:

- Spectrum licence owner: this actor owns spectrum that it wants to sell or lease on the spectrum market. Typical spectrum licence owners are TV broadcasters, wireless and mobile operators, the military, radar communications operators, public safety operators (health care, fire brigade, police), and aviation operators.

- Secondary or cognitive radio operator: this actor will participate in the spectrum market as a spectrum buyer or lessee in order to buy or rent spectrum. This will typically be a new operator without existing wireless spectrum licences that need spectrum to offer a wireless service. However, a spectrum licence owner (as in the point above) who needs more spectrum in order to serve increasing spectrum demand could also act as a secondary or cognitive radio operator.
- Secondary or cognitive radio device: this actor will have the same role as the secondary or cognitive operator, but will differ in that it is the radio device or end user that participates in the spectrum market as a buyer or lessee instead of the operator. This could be M2M communications such as wireless metering that rents spectrum for a very short period in order to transmit metering information.
- Spectrum speculator: this actor will participate in the spectrum market with the intention to make profit by buying spectrum at low prices and selling at higher prices. A spectrum market-maker as used in price driven markets will act as a spectrum speculator.

A *Spectrum Broker* in the spectrum trading market is analogous to a broker in the stock exchange market. The spectrum broker can then be defined as a party which arranges transactions between a buyer and a seller or leaser and lessee, and gets a commission when a deal is executed. A spectrum broker might have several additional properties such as providing market information about prices, spectrum details and market conditions.

No practical experience on spectrum brokerage exists, but in theory several different actors could operate a spectrum broker. A first option is that an independent third party operates the spectrum broker. The third party could either be a non-profit organization established by the regulator or it could be a commercial company aiming at profiting from running the spectrum broker. In both cases, the spectrum broker operator could be independent of the interests of the spectrum sellers or buyers. Another option is that the regulator operates the spectrum broker itself. As a third option, in the case where a spectrum licence owner wants to lease, he could operate the spectrum broker itself according to national regulatory rules in one geographical area or country.

A *Spectrum Database* contains information about the radio spectrum to be traded. This could be information about who owns the licences of the spectrum, who uses the spectrum, spectrum occupancy, spectrum availability, noise and interference conditions in a spectrum band, and so on. This information could be retrieved from sensor networks, geo-location database, wireless communication operators or it could be downloaded from databases held by the regulators. Different actors could operate a spectrum database. It could potentially be an independent third party, the regulator or the spectrum licence owner.

A *Wireless Sensor Network* (WSN) can be used to monitor the radio spectrum to be traded for a given area. The WSN can provide much of the same information as a spectrum database. In addition it can provide more detailed information about the real-time spectrum status (spatial, temporal and frequency) such as noise, interference and detailed location information of radio emitters. This information can also be reported (sold) to a spectrum database. As a potential solution to the problem of monitoring compliance of committed spectrum trades and that the spectrum trading regime is not misused, the operator of a WSN could act as spectrum police.

The *Spectrum Regulator* is interested in having a high utilization of the spectral resources and that people get high quality services. Since a spectrum market will simply access to spectrum and enable more dynamic use of spectrum leading to higher spectrum utilization, the regulator will be interested in this. However, with incautious regulation of a spectrum market there might be a risk that the spectrum market will lead to unfair spectrum allocations, increased interference and unhealthy competition. To mitigate this, the regulator can take the role as the spectrum broker. The main task of a spectrum regulator in a spectrum market will be to set out the rules, policies and processes that must be adhered to in a spectrum market.

Finally, both hardware and software vendors will be important in the ecosystem. For example, terminal, base-station and core network vendors are important in order to implement the required cognitive functionalities and trading functions in wireless networks. The vendor will also be important for implementing the spectrum broker, spectrum database and WSN.

Metrics for Spectrum Trading

A spectrum trading metric could be any type of measurement to quantify the performance of a spectrum micro-trading market. When studying the state-of-the-art on spectrum trading, it can be found that many different metrics are used to study the performance of the assumptions and models used. The QoSMOS project proposes that these main high level metrics should be used for assessing the performance of micro-trading:

- Market Viability: can micro-trading be a profitable business?
- Channel Quality: will QoS and Quality of Experience (QoE) (for example, channel throughput, latency and so on) be improved by micro-trading?
- Spectrum Utilization: will micro-trading make better use of available spectrum?
- Social welfare: will the general well-being of society be improved by using micro-trading?

The metrics might be specific to one or more of the roles and actors defined in the ecosystem; for example, social welfare could be specific to the regulator. These metrics are further divided into a set of sub-metrics used to measure performance at the low level.

For market viability, the most important sub-metrics to be measured are liquidity, sustainability, profitability, spectrum price and end user call/session blocking rate. To estimate the channel quality, the sub-metrics are the allowed transmit power and propagation effects for the secondary system, and interference and throughput for both the primary and secondary systems. Real-time spectrum utilization can be measured by finding the total spectrum blocks being used, number of blocks being offered for sale in the market and the spectrum allocation effectiveness. The social welfare could be measured by defining a social welfare function that ranks conceivable social states: for example, complete descriptions of the society, from lowest to highest.

Conclusions

For cognitive radio technology to be attractive, it has to prove itself in the wireless marketplace. This White Paper from the EC project QoSMOS has identified the criteria for feasible deployment and described some possible business cases for cognitive radio.

Some of the most interesting business opportunities are the access to the wireless market for new entrants and well as benefits for existing wireless operators. Some examples are easier access to new markets, capacity enhancements, spectrum sharing, spectrum trading, cost and performance gains in existing networks and new services.

The QoSMOS project has defined several criteria to find feasible deployment scenarios for cognitive radio systems addressing both technical and commercial factors. The resulting promising scenarios are cognitive femtocells, cellular extension in whitespaces including rural broadband and cognitive ad hoc networks.

Spectrum trading can be combined with cognitive radio to create a market place for micro-trading. An ecosystem for spectrum trading will consist of spectrum traders, spectrum brokers, spectrum databases and a spectrum regulator. In addition, a wireless sensor network may be implemented to provide more detailed information about the real-time spectrum status. Fair trading is dependent on well-defined trading metrics which are quantifiable measures of the performance of the trading market. Recommended high levels metrics are market viability, channel quality, spectrum utilization and social welfare.

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References

[1] FP7-ICT-2009-4- 248454 QoSMOS Project, http://www.ict-qosmos.eu/.

[2] FCC. *Unlicensed operation in TV Broadcast Bands, Final Rules*. Federal Register / Vol. 74, No. 30 / Tuesday, February 17, 2009 / Rules and Regulations, 7314-7332. [online], URL: http://edocket.access.gpo.gov/2009/pdf/E9-3279.pdf

[3] FCC. *In the Matter of: Unlicensed Operation in the TV Broadcast Bands; Additional Spectrum for Unlicensed Devices Below 900 MHz and in the 3 GHz Band. Second Memorandum Opinion and Order*. FCC Doc 10-174, 23 Sept 2010. [online], URL: http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-10-174A1.pdf

[4] Ofcom. Digital Dividend: Statement on licence-exempting cognitive devices using interleaved spectrum. 1st July 2009. [online], URL: http://stakeholders.ofcom.org.uk/binaries/consultations/cognitive/statement/statement.pdf

[5] Ofcom. Implementing Geolocation – Summary of consultation responses and next steps. 1st September 2011. [online], URL: http://stakeholders.ofcom.org.uk/binaries/consultations/geolocation/statement/statement.pdf

[6] 3GPP. *TSG RAN; E-UTRAN; Self-configuring and self-optimizing (SON) use cases and solutions (Release 9)*. 3GPP TR 36.902 V9.3.1. March 2011.

[7] MacKenzie R (ed), Lehne P H, Celentano U, Ariyoshi M, Cendón B, Medela A. *QoSMOS Consolidated Scenarios*. QoSMOS deliverable D1.2. December 2010, http://www.ict-qosmos.eu/fileadmin/documents/Dissemination/Deliverables/files/DelPub/QoSMOS_WP1_D12.pdf

[8] MacKenzie R, Lehne P H, Celentano U, Ariyoshi M. Identifying Scenarios with High Potential for Future Cognitive Radio Networks. *Future Networks & Mobile Summit 2011*. Warsaw, 15-17 June 2011.

[9] Legislation.gov.uk. *The Wireless Telegraphy (Spectrum Trading) Regulations 2004*. Nov. 2004. [online] URL: http://www.legislation.gov.uk/uksi/2004/3154/pdfs/uksi_20043154_en.pdf

[10] FCC. *In Matter of Promoting Efficient Use of Spectrum Through Elimination of Barriers to the Development of Secondary Markets (WT Docket No. 00-230), Report and Order and Further Notice of Proposed Rule Making.* FCC Doc 03-113. 6 Oct 2003. [online] URL: http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-03-113A1.pdf

[11] FCC. *In Matter of Promoting Efficient Use of Spectrum Through Elimination of Barriers to the Development of Secondary Markets (WT Docket No. 00-230), Memorandum Opinion and Order.* FCC Doc 04-239. 30 Jan 2004. [online] URL: http://hraunfoss.fcc.gov/edocs_public/attachmatch/DA-04-239A1.pdf

[12] FCC. *In Matter of Promoting Efficient Use of Spectrum Through Elimination of Barriers to the Development of Secondary Markets (WT Docket No. 00-230), Second Report and Order, Order on reconsideration, and second further notice of proposed rulemaking.* FCC Doc 04-167. 2 Sept 2004. [online] URL: http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-04-167A1.pdf