Comparison of Smart Grid with Cognitive Radio: Solutions to Spectrum Scarcity

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***Abstract*- Cognitive radios (CRs) have recently attracted attentions as an alternative to the problem of spectrum scarcity. The main principle of these radio networks is opportunistic access to the spectrum holes mainly licensed to primary users (PUs). Within power systems, on the other hand, smart grid is one of the main areas of research. The core aspect of these grids is making use of digital technologies to save energy, reduce cost and increase reliability and transparency in order to optimize the utilization of the available resources. Since scarcity of resources is the crisis of both communication systems and electrical energy systems, in this paper, comparing the smart grids with communication systems in general and with CRs especially, solutions for the problem of spectrum scarcity will be explored.**

***Keywords*— Cognitive Radios, Smart Grid, Spectrum Scarcity**

I. INTRODUCTION

Traditional licensing policy has led to the problem of spectrum scarcity. This has motivated researchers to seek for such solutions which do not need a fixed frequency bandwidth as Cognitive Radios (CRs) that operate based on opportunistic access. In order to get the most out of spectrum resources, however, convenient development of CRs in one hand and understanding the capabilities of Cognition on the other, are key points. Parallel to communication researchers, many other entities are trying to optimize their resources among which power systems' researchers are one. As a very important solution to the optimization of their networks, they have recently offered the idea of smart grid. Since both bodies, i.e., communication systems and electrical energy systems face the same problem, i.e., shortage of resources; comparison between them can give both sides to come up with new ideas for better designs. In this paper, paralleling the smart grids with CRs, it has been tried to first explain the duality of solutions in both sides and then suggest ideas for the problem of spectrum scarcity. To do so, the structure of the paper will be as follows. In the next section, the main functions of smart grids will be stated in brief. Also, here, along with their counterparts in communication systems in general case and CRs in special, these functions will be explained in more details in order to understand the new resources of spectrum. Finally, section III concludes the paper.

II. FUNCTIONS OF A SMART GRID

According to the United States Department of Energy's Modern Grid Initiative report [1], a modern smart grid must:

- Be able to heal itself
- Motivate consumers to actively participate in operations of the grid
- Resist attacks
- Provide higher quality power that will save money wasted from outages
- Accommodate all generation and storage options
- Enable electricity markets to flourish
- Run more efficiently

A. Be able to heal itself

An electrical energy system must be able to react against faults and repair itself. This situation occurs, for example, when a transmission line or substation is affected by such fault as short circuit and have to be isolated from the rest of the network for a while. The self-healing feature, here, refers to the ability of network to detect the faulted area based on the gathered information from appropriate sensors and supply non-faulted points through alternative routes. For example, within a radial network, upon experiencing fault in a point, the rest of the network towards customer will lose their electricity, while in a mesh configuration, dependent on the capacity of lines, it is possible to bypass only the faulted point and likely no customer experience outage (see fig. 1). Though not frequent, outage of high-capacity lines or substations may even result in the overall outage of electricity. This occurs in an interconnected network when dependency on a few energy resources or transmission lines is high. In this case, in fact, what a smart grid intends to provides the electrical networks with is increasing the reliability.

Such situations as those just mentioned in case of electrical energy, though maybe not to that extent, are likely in a communication network, too. Therefore, here, in order to increase the reliability of a communication link, several routs to specific points will be considered. In other words, the mesh configuration will be preferred to radial or star graphs.

The reliability of a network may be assessed in two levels: hardware and software. In hardware, the overall configuration

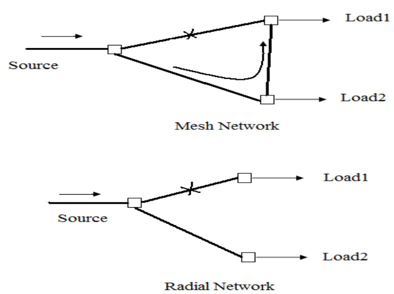

Fig. 1: Comparison of Reliability of Mesh and Radial Configuration

of the network as well as each individual device should be of sufficient reliability. For example, number of articulation points in the graph of the network and the measure of Mean Time Between Failures (MTBF) can be considered for the reliability of the network graph and individual part, respectively. In software level, network must be programmed in a way so that compensate for the weak-points of the hardware. In this level, reliability of the network can be improved by two factors:

- Existence of information gathering systems from various parts of the network especially the strategic and critical points. When sensory and measurement systems are well designed and capable of transferring their data to a processing brain using an efficient communication system, the final result will be efficient.
- Algorithms capable of offering best alternatives towards improvement of deficiencies. The corresponding decisions can be made as either centralized or decentralized. Fault positioning and reconfiguration algorithms, in this respect, will play the role of system's brain to provide reliability.

In case of communication systems, providing the reliability based on parallel networks is possibly costly. However, the decentralized algorithms still can be seen as an alternative. From another point of view, the idea of inserting *cognition* in communication transceivers may provide other solutions. according to [3], a cognitive radio is defined as: *an intelligent wireless communication system that is aware of its surrounding environment (i.e., outside world), and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variations in the incoming RF stimuli by making corresponding changes in certain operating parameters (e.g., transmit-power, carrier-frequency, and modulation strategy) in real-time, with two primary objectives in mind:*

- *Highly reliable communications whenever and wherever needed;*
- *Efficient utilization of the radio spectrum.*

The idea of cognitive radios is presently aims at utilization of spectrum holes mainly dedicated to PUs using a new Cognitive Radio Network (CRN). Thus, a single CR or even a few numbers of them would not be able to provide the goals mentioned in [3], even in presence of many communication systems almost everywhere. In other words, if cognitive radios be capable of and allowed to operating with the available systems when they are unused, new resources would appear. According to [3], most of TV bands are busy less than 25% of times. When the corresponding systems don't use the channel, most of their equipments are idle, too. Thus, those with capability of relaying data can be seen as another resource. Since TV systems are almost present everywhere, the idea can be completely interesting. If this happens, higher reliability in terms of higher data rates and new alternative route will be provided. However, inserting this capability creates new problems that should be addressed. Among these, two most important ones are:

- Ability of CR to speak with the language of present systems. In other words, CR must either know the current protocols or be able to learn them.
- Determining the limits of CR's operation when it works with other systems. In the present idea of CRs, the Maximum Interference Temperature (ITmax) is the upper bound for the interference that CRs are allowed to create for PUs with their transmissions. However, if they get permission to use the PUs' equipments, too, the limits should be changed so that considers other probable problems among which may be the most important one is security.

B. Motivate consumers to actively participate in operations of the grid

One of the most problematic issues in electrical energy systems is the difference between generation and demand in different hours. In other words, in some hours, demand is lower than generation while especially in peak hours, the situation is inverse. The common solutions to this are:

- Encourage and force the customers to adapt their demand to generation using such policies as multi-price energy meters (see fig. 2[5]) and load shedding. In this case, the convenient delivery of consumption information of customers to them would be a great help to the demand adjustment.
- Use of distributed generations in terms of small power plants. Since mass production of energy in limited spaces would damage the natural resources in one hand and increase the transmission loss on the other, such small distributed generations as solar cells and micro-turbines would be a great help [1,2] (see fig. 3). Since such power plants can be small enough, many social institutions and even customers can be equipped with them. Thus, the more distributed generation plants, the less problematic issues of mass generation plants. However, the effects of DGs' dynamics on such

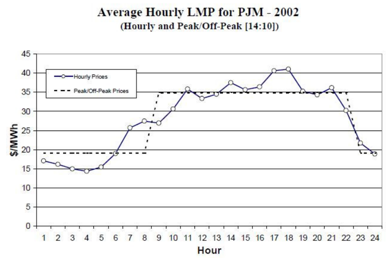

Fig. 2: Adaptation of energy price to the level of demand in peak hours [5]

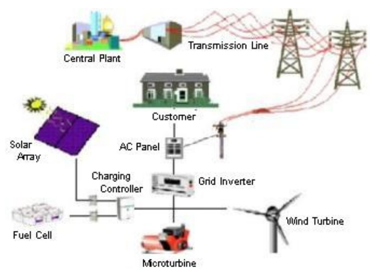

Fig. 3: Cooperation of distributed generations with mass production plants [6]

Quality of energy Parameters as dynamic and frequency stability of the whole network are key factors in their successful usage.

Our daily experiences show that the demand curve of communication services has a similar routine as that in fig. 2. In other words, in some hours of a day, service demand is so high that it either results in low quality of service in such communication services as internet in terms of higher waiting time or larger end-to-end delay, or high probability of blocking in such networks as cellular, especially in downtowns. As an example to this, fig. 4 shows the probability of blocking for a new customer in a cellular network. Assuming X, the random variable of the number of service requests, follows a Poisson distribution with parameter λ, the probability of blocking would be:

$$Prob(Blocking) = Prob(X > N_0) = \sum_{i=N_0}^{\infty} \frac{e^{\lambda(t)}(\lambda(t))^i}{i!} \quad (1)$$

where N_0 is the maximum number of users that can be serviced simultaneously. Fig. 4 depicts the probability of blocking a new user for two scenarios. In the first case, the demand pattern follows a uniform style while in the second scenario, demand changes with time. In comparison with electrical energy systems, of course, there are similar solutions in communication systems. Although the load control is not appropriate here, but convenient delivery of customers bids can be still an alternative. As the corresponding systems to DGs, cognitive radios and ultra

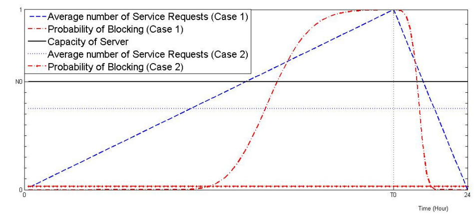

Fig. 4: Comparison of user's blocking probability for two styles of demand: uniform and variable with time

wide-band communication can be mentioned. With these technologies, utilization curve of spectrum resource would change from momentary and impulsive to more uniform. Of course, this does not mean that the channel behaviour would be less impulsive, but it implies that the channel will be used more complete.

One main problem before the realization of CR and UWB is the prediction of interferences that they would cause for the present applications. In other words, their existence with PUs must not cause destructive effects. Thus, these technologies along with their underlay networks must be able to analyse the effects of their operations on PUs. What seems certain in this respect is that the more exact and real samples of the frequency spectrum pattern of CRs and PUs in wherever they intends to coexist are available, prediction of the results would be easier. It can be imagined that a wireless sensor network (WSN) would be a great help to this goal. This can be achieved by encouragement of customers to play as small service providers, since customers themselves due to their geographical positions can provide the best samples of for interferences present for them.

Cooperation of customers can be helpful in two ways:

- Establishment of a sensor network for interference temperature assessment at PUs. Installing a single sensor by each customer, for example, can provide an ideal network for interfering effects of CRs on PUs.
- Utilization of places with lower interference temperature and wherever in which transmission of CRs would not cause excessive interference for PUs. Since the population and thus, service demand is not uniformly distributed over different geographies, customers' cooperation would be a help to spatial spectrum resources, too. Fig. 5 shows the distribution of interference in a given area. It can be seen that the lower crowded areas face lower interference than that of more crowded areas. This means that if transmission of a new user would not cause excessive interference for others, which is more probable in lower dense regions, it is allowed. Although there are such spectrum resources, their utilization cannot be realized without extensive cooperation of those who live there.

C. Resist Attacks

Resistance against attacks is the ability of network to recognize and locate attacks and proceed appropriately to prevent them before they affect the network. For this to happen,

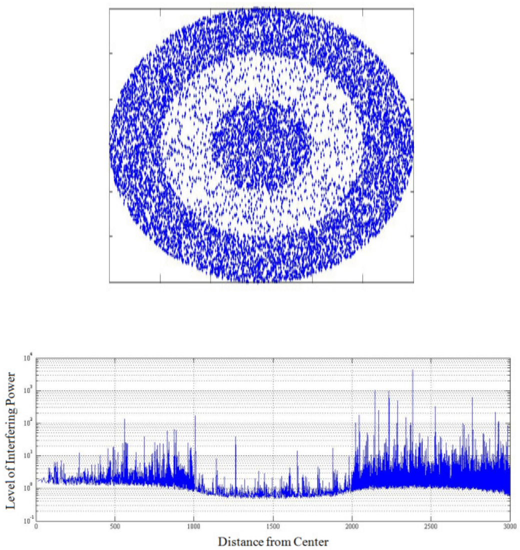

Fig. 5: distribution of CRs in an area with the corresponding electromagnetic power distribution versus distance from center

the existence of an information sensor network with suitable coverage is necessary. Such attacks in electrical systems are energy and equipment theft which can be easily detected through power measurements in the specific points.

In communication systems, attacks are common although with different face. Spy systems, for example, try to steal information. These kinds of attacks have been addressed thoroughly in texts (see for example [7-11]); however, with entrance of CRs, it can consist of other forms, too. For example, even with existence of amateur bands, some entities may intentionally or not, not consider frequency limits and interfere with others. Depending on the extent and intentions, this may affect from a few number of CRs to large number of them for either short or long times. One example of this is a powerful jammer in the same frequency of CRs which is located near the main server. Resistance to these kinds of attacks involves in presence of two capabilities in CRs:

- Realize the intentional or unintentional destructive signals from their own ones and PUs'.
- Locate the source of attacks

D. Provide higher quality power that will save money wasted from outages

According to [12], Outages and power quality issues cost US businesses more than \$80 billion on average each year. In the case of electrical systems, the quality of energy points to quality of the delivered frequency and voltage and the level and rate of electricity outage. The same situation, of course, is true in communication systems with quality of service's parameters as data rate, delay, probability of error and availability. One main reason for low quality of electricity is the weak monitoring of the underlay network. In many cases, electric companies become aware of problems in their networks only when customers complain. This situation might not cause difficulties in the past; however, with the existence of competitive markets, customers tend to service providers with higher qualities. The solution to this problem is installing such monitoring devices as sensors and processors that run the fault positioning algorithms.

The corresponding problem in communication systems can be even worse, since customers can evaluate their quality of service in term of guaranteed data rate, delay or probability of blocking; while in electrical systems, this evaluation, in many cases, involves in measurement devices and complicated deduction. On the other hand, with the entrance of CRs and coexistence policy of applications, higher level of interference can be imaginable. Thus, in order to alleviate the costs of low quality of service, service providers must, beside a suitable design, be able to analyse their quality of service in minimum possible time and proceed appropriately to improve them. As mentioned before, electric companies have found smart sensors and efficient communication systems a necessity for solution to this problem. Thus, communication researchers who present such solutions for other applications, possibly have to view their own productions differently.

E. Accommodate all generation and storage options

In smart grids this item is to be realized in two forms:

- Utilization of any possible production methods in which last of them points to DGs and such renewable energy resources as fuel cells, micro-turbines and fuel cells.
- Reserve energies in terms of batteries, hydroelectricity and superconductors.

The corresponding solutions in communication systems may include all multiple access methods including FDMA, TDMA, CDMA, besides OFDM, array and directional antennas. Recently, also, CRs have been proposed to follow the multiple access methods more efficiently. Since spectrum limitation is the results of interference between co-channel simultaneous signal transmissions in the same geographical place, any frequency, time and space holes can be seen as spectrum resources. Utilization of such frequency bands as SHF and EHF has already responded to the spectrum demand to some extent; however, since the electronics capable of operation in these frequencies still have not well found their broad places in communication systems, their capacities may not be used completely. In addition to time and frequency holes, another available resource which has become usable, thanks to the introduction of Interference Temperature limit, is the spatial holes. In this respect, directional antennas along with spatial routing algorithms may be used to benefit from such spatial holes as that of fig. 5. Fig. 6 shows the result of applying the simple following routing metric for utilization of spatial holes:

$$C_i = n_i \times d_i, i = 1, 2, \dots, M \tag{2}$$

where n_i is the number of neighbours of the i^{th} node among the surrounding nodes and d_i is the distance of this node from destination.

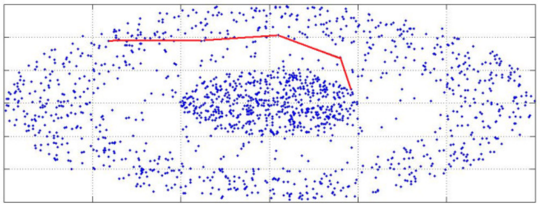

Fig. 6: Sample routing for users in figure 5

Although CRs presented the idea of available idle times, however, they can utilize only a portion of these available resources because:

- A great number of users demand for service during certain hours, while there are great idle resources at night times.
- Since the primary owners of the spectrum are PUs, their statistical behaviors affect the available resources for CR to a high extent.

Apparently, the maximum utilization would be achieved only when PUs behaviours are deterministic. Even if some PUs have nearly deterministic behaviours, there is no guarantee for following the same routine in the future. Providing some facilities for PUs can partly improve their behaviour. For example, many of the programs on TVs such as movies, serials and scientific programs are not live. While performing the live programs needs online broadcasting, non-live ones can be communicated at night times and restored in hardware. The revolution in electronics can realize this solution easily. If this happen, not only CRs would have more opportunities, for PUs will be present less than before, but also their works would be easier since they would less worry about the interfering with them.

F. Enable electricity markets to flourish

Since increase in electricity transmission and production capacity in massive amounts involves in high costs and complicated management, encouraging the energy markets using the public intelligence and money would alleviate this situation very much. The more public cooperate, the easier the goals will be achieved. Their success, of course depends on networked sensors and software which are capable of analysing the effects of different parts on the whole system; otherwise, these may make the quality of energy severely questionable.

Responding to the daily increasing demands for communication services, certainly seeks for public cooperation and encouragement. Today, there are large numbers of communication systems of a wide variety of protocols. Increasing number of communication systems with their specific protocols in one hand and traffic of applications in frequency spectrums on the other would make the future systems doubly complicated. In case of CRs, the situation may be worse. First, their operation is based on opportunistic access and non-interfering. Second, the first customer candidate for CRs are the far countries where installing a new communication systems is not monetarily reasonable because of low population, high dispersion and lack of cultural context for acceptance or demand for such communication services as internet. This implies the need for public cooperation in terms of spectrum markets. For these markets to flourish, the opportunity of applying their successful experience to new channels other than TV bands can be granted, too.

G. Run More Efficiently

An efficient electrical system benefits from the cooperation between various parts in establishment of the optimal load flow, decreasing the investment and maintenance costs along with reduction in bottlenecks and traffics. This cooperation, for example, may lead to supply a region using a nearby plant instead of a farther one or supply a specific area by farther plant instead of establishment of new plants.

This item in communication systems, until now, has been followed in various forms. For example, when cable systems are costly, wireless alternatives come into handy and where the terrestrial wireless systems don't provide enough coverage, satellite communications is a solution. However, communication systems are still treated as individual systems. The entrance of CRs can be seen as the first step towards the cooperation of different protocols. Refereeing to fig. 4 shows that only a small portion of times the full utilization of installed equipments is realized. However, the optimal usage of the resources needs more cooperation. Since most of the existing communication systems are application oriented, thus, difference between protocols would be the first obstacle before this cooperation. In order to eliminate this problem, the prerequisites mentioned in section *A* should be inserted in the future communication systems.

III. CONCLUSIONS

Communication systems and electrical energy systems, although in different areas, face the same problem, i.e., scarcity of resources. In this paper, comparing these networks in general and smart grid with cognitive radios especially, it was tried to analyse and suggest solutions for the problem of spectrum scarcity.

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