Academic Science

International Journal of Electronics, Electrical and Computational System
IJEECS
ISSN 2348-117X
Volume 6, Issue 8
August 2017

Cognitive Radio Channel Allocation and Traffic Scheduling Scheme For System Utility Optimization For Smart Grid Communication System

K. Balakrishnan, S. Tamilarasan, Bharath Raj D., Rakesh B. S.
Brindavan College of Engineering

ABSTRACT

Smart Grid (SG) can be thought of as an evolved grid system that can manage electricity demand in a sustainable, reliable and economic manner built on advanced infrastructure and tuned to facilitate the integration of all involved. In combination with wireless multimedia sensor networks, smart grids are capable of providing information related to energy resource monitoring, security, grid failure detection, and recovery from the failure and so on. Cognitive Radio (CR) is a wireless technology which is intelligent and plays a key role in improvisation of efficiency of the bandwidth available. The capability of CR to reduce communication interferences makes it essential to use CR in smart grid systems. In this paper, we propose a CR based smart grid system which is priority oriented. We will be proposing a channel allocation scheme based on CR and traffic scheduling schemes. The proposal takes into consideration spectrum sensing errors and channel switch. The results of the proposal are demonstrated though simulation results.

KEYWORDS

Smart Grid (SG), Cognitive Radio (CR), Traffic Scheduling, Channel Allocation

INTRODUCTION

A Smart Grid (SG) system is an intelligent system which basis itself on the concept of efficient power exchange and delivery, by using communication platforms to optimize the operation of units that are connected to one another. Through SG systems, remote monitoring and control of electricity usage can be accomplished. Unauthorized usage can also be detected and prevented. Through SG systems, the system reliability, efficiency and safety can be improved.

In combination with Wireless Sensor Networks (WSN), Smart Grids become a potent force, where low cost sensors of the WSN can be used to collect information about the behavior of the power equipment that are located remotely. This information can then be used to manage the power grid. The sensors of the WSN perform tasks like remote site monitoring, automatic meter reading and so on.

Further, Wireless Multimedia Sensor Networks (WMSN) give better monitoring options for SGs as these networks use visual and acoustic sensors for monitoring the grids. With the use of multimedia sensors, there is an increase in the requirement of bandwidth and network resources as these sensors capture and transmit multimedia data. This results in need of a technology that can efficiently utilize the bandwidth available. One such technology is CR which the very efficient when it comes to spectrum usage. This makes smart grids with CR a powerful combination.

One important challenge faced in SG systems is how to manage the traffic and interferences that occur when a huge amount of system monitored multimedia data is transported through the grid infrastructure. This calls for high bandwidth requirement for smooth transportation, otherwise there will be a lot of congestion. We propose a Traffic Scheduling scheme that can support different traffic types in smart grid including multimedia over SG. This is accomplished using CR in combination with SG infrastructure.

LITERATURE SURVEY

One of the primary reasons for smart grids being so beneficial is its capability to return clean energy back to the grid. This can be illustrated with the following real time example of an electric car. A car which is fully charges is capable of providing electricity back to some home appliances when there is no power available or when the electricity is very expensive. To have such functions, real time sensing, data collection and communication of collected data is very critical. In order to handle such data from large number of power grids smoothly, either we need a large network bandwidth or we need an approach where the existing bandwidth can be efficiently utilized. The first scenario is very expensive and the latter is accomplished using CR.[1][5]

Puri et al and Majumdar et al have proposed an approach where the video packets from the sensor can be sent through multiple secondary channels available. They have proposed a method for dynamically selecting CR secondary channels for transmitting multimedia data in a distributed manner.[6] Niyato et al and Hossain et al have conducted a survey on how CR can be applied to future generation networks.[13]

Wan et al has surveyed the application of CR in conjunction with smart grid. They have proposed that the capability of CR to effectively utilize the free bandwidth helps in the timely exchange of information in SGs.[4][9] A sensing and delay trade off problem for communications in CR enabled SG has been formulated and solved by Zhang et al and Chau et al.[10] Milstein et al and Vaman et al have proposed an approach that avoids interference of Secondary Users(SU) with the existing Primary Users(PU) with respect to resource allocation in mobile adhoc networks.[14]

Another resource allocation scheme which is based on OFDM CR networks is proposed by Zhang et al and Leung et al.[2] Gungor et al, Lu et al and Kato et al have surveyed the possibilities of applying Wireless Sensor Networks in SG systems to improve the monitoring capability of the system. They have concluded that an intelligent monitoring platform can be created using the two technologies.[12][15][3]

With multimedia surveillance in SG systems, the transmission of such multimedia data over CR networks is very critical as the multimedia quality must be maintained. Whu et al and Tang et al have proposed a cross layer design that upholds the multimedia quality during transmission.[7] Mansour et al and Krishnamurthy et al have proposed multi user transmission control of scalable video to improve the video quality.[7][11][8]

ARCHITECTURE

In the proposed system, the spectrum is made up of K channels with equal bandwidth. These channels are shared by P PUs and N SUs. The SUs are arranged into S classes based on their priority. All the SUs send information to the CR base station. All the users in the CR network are categorized into $S+1$ levels of priority. In this categorization, the priority of PUs is 0. In the considered example, there are three classes of priority (S=2). The priority levels are L_0, L_1 and L_2. Based on the availability of the resources, the base station informs the SUs about channel availability. The SUs are informed about the channel availability based on their priority.

Each SU maintains a queue in which the packets reside, arranged based on their priority. On the availability of the channels, these packets are transmitted by the SUs. An SU can use a channel for packet transmission as long as no PU returns. On return of a PU, the SU must return the channel to the PU.

In the proposed system, the network is considered as $\Omega(P, N)$ where $P=\{p_1,p_2,\ldots\ldots p_P\}$ are the PUs and $N=\{n_1,n_2,\ldots.n_N\}$ are the SUs. All these users are connected to the base station. An assumption that we make is the number of channels in the spectrum is same as the number of PUs. This means there are P channels. The SUs are categorized based on their priority as $\{SU_1, SU_2,\ldots,SU_S\}$. Within each SU, the packets are classified into M classes based on the packet priority. Lower the value of M, greater is the priority. The availability of channels for an SU is represented using a Resource Matrix R_n. The various factors that influence the availability of a channel to a SU are interference, sensing errors and channel switching interferences which are presented in detail in the following sections. The schematic representation of the system architecture is shown in Fig 1.

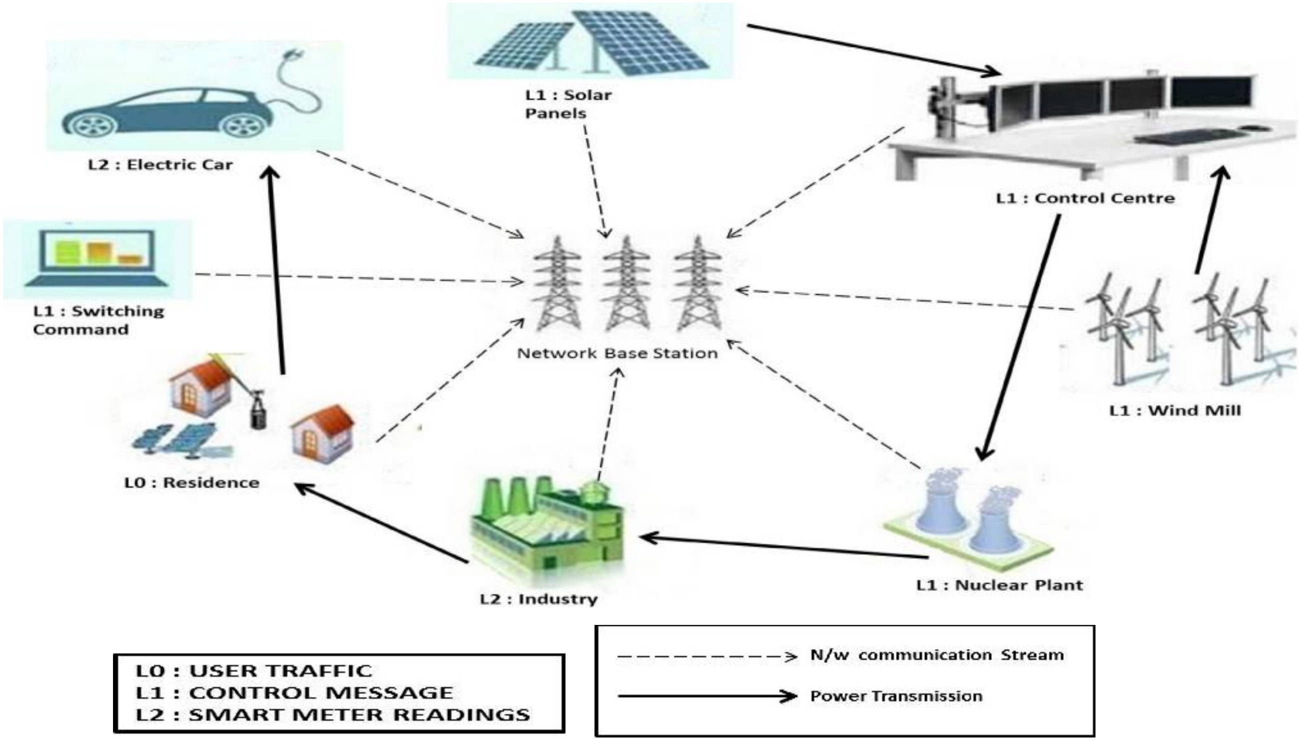

Fig. 1 System Architecture

Types of Interferences

For a SU, interferences during channel allocation can occur majorly in four different forms:

(i) From PUs
(ii) From higher priority SUs
(iii) Due to Channel Switch
(iv) Due to Sensing Errors

(i) Interference from PUs

When a SU is using a channel for transmission and a PU appears, it is the SU that needs to stop transmission and return the channel to PU. SUs are dropped from the queue to access channels on return of a PU. To avoid such interferences for the SUs, a Spectrum Availability Matrix (SAM) is defined for the SUs in CRN. For a secondary user SU_n, its SAM is represented as Z_n.

(ii) Interference from Higher Priority SUs

If there is one SU that has occupied a channel for transmission and if this SU has a priority greater than some other SUs that also have occupied channels for transmission, then the higher priority SU can cause interference to other SUs in the network having lower priorities. If SU_k is a SU with high priority and it is causing interference to another SU say SU_i, then this interference is defined by a Channel Resource Matrix for SU_i.

Also, an Interference Matrix, given by I_k is defined for SU_k which is defined as

$$I_k = [\, I_i \,] \in \{\, 0,1 \,\}^{1*P}$$

$$I_t = \begin{cases} 1, & i \; c \quad i\,c \quad b \quad i \quad b \quad S \\ 0, & o \end{cases}$$

(iii) Interference due to Channel Switch

When a SU is using a particular channel and if a PU or another SU with a higher priority appears, then this SU must give away the channel that it is currently using and look for another channel so that it can continue with its transmission. This process of moving from one channel to another by a SU is called Chanel Switch. Every

SU will have sensors using which they determine existence of other available channels. These sensors look for what are the available channels, the channel quality and the duration for which the channel is available.

These sensors will have energy which is used to perform sensing. Higher the energy available at the sensors, greater the range covered to detect available channels and vice versa. Hence, we can conclude that based on the energy levels of the sensors, the range of the search for channels is determined. Greater energy level in the sensor means wider range is covered. Channel switching can happen in two ways:

1) Periodic Switching (PS) – In this case, when a SU loses a channel, it simply waits till it gets a notification about other channel being available. The SU remains idle until it receives any such notification.

2) Triggered Switch (TS) – here, when a SU loses a channel, it gets a notification immediately about some other channel being held by a lower priority SU, if any. This SU can then switch to that channel. If TS is used, there will be a lot of interference in transmission for lower priority SUs and lower priority packets as the higher priority SUs overpower the other lower SUs and occupy the channel. Also since TS approach gives immediate notification about channel availability, it means that the sensors of such SUs are always active, which results in more energy consumption. Due to these reasons, the decision of using PS or TS depends on the current energy levels at SU sensors and the channel availability probability.

If P_T is the probability of using TS approach and P_S is the probability that a SU switches channels, the interference cause by the TS approach is represented using a matrix denoted by SI_k and is given by,

$$SI_k = [\, SI_i \,] \in \{\, 0,1 \,\}^{P}$$

$$SI_i = \begin{cases} 1, \quad i\; P\,.P > \sigma\,,\ c \quad i\,o\ \ s\,n \quad n \\ c \quad b\ \ i \quad\quad b\ \ a\,h \quad p \quad S \\ 0, \quad\quad\quad\quad o \end{cases}$$

where σ_i is the upper limit to control channel switching by a higher priority SU.

(iv) Interference due to sensing errors

If the sensing of available channels is perfect in a CRN, the spectrum utilization will be very efficient. However, there are certain factors that make perfect sensing impossible. These factors include presence of attenuation in signal, limited energy levels of sensors. These factors lead to error in sensing that can affect the transmission of PUs and SUs.

Sensing can either be False Alarm or Missed Detection. If H_1 denotes that a channel is occupied by a PU and H_0 denotes that a channel is free, False Alarm is the phenomenon where a free channel is detected as busy and Missed Detection results in detecting an occupied channel as free. Let P_f denote the probability of False Alarm and P_m denote the probability of Missed Detection. The Sensing Error of a higher priority SU, say SU_k is given by

$$SR_k = [\, SR_i \,] \in \{\, 0,1 \,\}^{1XP}$$

$$SR_i = \begin{cases} 1,\ i\ \ P \quad > \tau\,,\ m \quad d \quad h \\ \quad i\ \ s \quad r \quad o\ \ n \quad n \\ 0, \quad\quad\quad\quad o \end{cases}$$

(v) The Resource Matrix

The availability of channels for various nodes in represented using a Resource Matrix, R_n. This matrix is obtained by exchange of information between neighboring nodes. For a SU node *n* with priority *k* and its packet priority *m*, the resource matrix is represented as $R_n^{m,k}$ and is given by

$$R_n^{m,k} = Rn \bullet Z^{-1}{}_{n} \bullet I^{-1}{}_{k-1} \bullet \ldots \bullet I^{-1}{}_{1} \bullet SI^{-1}{}_{k-1} \bullet \ldots \bullet SI^{-1}{}_{1} \bullet \ (SR^{m}{}_{k-1})^{-1} \bullet (SR^{m}{}_{1})^{-1}$$

SYSTEM UTILIZATION AND QUALITY CONTROL FOR CR BASED SG SYSTEMS

There is a big challenge when it comes to transmission of multimedia content over a wireless network. Several parameters such as bandwidth, delay determine the quality of such transmission. These parameters are referred to as QOS parameters. Due to very high demand for video streaming over wireless networks, managing these

QOS parameters has become very important factor in SG communication systems. If the QOS of video streaming is properly managed it will have a positive influence on the user with respect to perception of service. The criteria that matters to an end user with respect to video streaming are security, cost, continuity flexibility and mobility. If these factors are properly managed, then the end user will have a satisfactory experience of video streaming. The quality of such service can be evaluated based on parameters like the blocking and dropping probability of SU.

(i) Multimedia Quality Modeling

There are two main reasons for a multimedia data to get corrupted during transmission over wireless medium. They are Source Coding Distortion and Transmission Distortion.

In Source Coding Distortion, the media information to be transmitted is encoded by the sending node. This encoding process compresses the data, thus reducing the load for transmission. Due to this compression of data at the source node, there are chances of some data being lost which leads to distortion.

In Transmission Distortion, the data loss occurs due to the factors affecting data transmission in the wireless transmission environment. Some reasons for such a distortion include loss of packets, noise interference.

Transmission Distortion

The SUs are categorized into several classes. This classification is performed based on priority. Hence the SUs are allocated channels based on their priority. Also the quality of channels varies based on the priority of the SUs. Hence, the lower quality channels are prone to disturbances which in turn lead to distortion. For each frame, the quality can be calculated based on two parameters, P_{loss} (probability of packet loss) and $P_{success}$ (probability of successful packet transmission).

As already discussed, the main reasons for a packet loss in a CRN are Packet Error with Packet Error Rate $P_{e,}$ interference by channel switching with probability $P_T.P_{S,}$ Interference by sensing errors with probability P_M and the probability that the packet transmission exceeds delay bound P_{delay} given by $P_r\{ d_{ij} \geq D_{ij} \}$. Based on these factors, the overall probability of a packet being lost can be given as

$$P_{loss} = P_e \,.\, (P_T \,.\, P_S) \,.\, P_M \,.\, P_{delay}$$

We now proceed to the calculation of quality of a frame which involves two major phases. The first phase is distortion reduction of frame due to successful packet transmission where, if a packet is successfully delivered to its destination, then we conclude that the only distortion that this packet has is the distortion included at the source node, which is represented as D_{source}. The second phase is distortion reduction of frame caused by lost packets. This parameter is calculated by computing the SNR of the frame such that all the packets in it except the current one are decoded losslessly and the current packet is considered to be lost.

(ii) Cognitive Radio Utilization for Smart Grid

Understanding how CR systems use SG is accomplished by studying three models as follows:

Primary User Arrival Model

This model is totally based on the arrival of PU and what measures can be taken so that the secondary transmission is not disturbed on the primary rearrival. Here we consider a Secondary Channel(SC) used by a SU to transmit some data. During transmission, if there is any interference by a PU, the transmission of data results in loss of video packets. Now the SU needs to create and send a failure notice to the sender requesting for retransmission of remaining packets. In the CR systems, the retransmission is avoided using a low density parity check error correcting method. In this approach, the video to be transmitted is converted into a group of pictures. This is accomplished using a compressed video transmission application. Once the video is converted, the SU then selects an appropriate SC based on the quality of available SCs. Once chosen, transmission begins on the selected SC. In this process, the arrival rate of a PU_j is defined to be σ_j. Hence the mean arrival rate of a PU is given by μ_j=1/ σ_j. The simple principle of this model is, if the secondary transmission completes within time $\mu_{j,}$ the transmission is considered successful. If the transmission is happening and a PU reappears, the complete transmission is considered a loss.

Secondary User Arrival Model

In this model, we derive the arrival rate of the secondary users. The arrival rate of SUs is related to the source coding information where source coding means encoding the information at the source before they are transmitted. Here we assume that the source information bits are encoded at a rate of R_{si}. Also, let the number of bits from a SU_i is a constant , given by D_i. Then R_{si} gives the number of source packets that are generated in the time T_{si}. This defines the arrival rate of a SU_i which is given by,

$$\lambda_i = \boldsymbol{D} \;/ (\boldsymbol{R} \quad . \; \boldsymbol{T} \quad)$$

Hence we can conclude that the arrival rate of SU can be determined based on the source coding time distortion T_{si}, source coding rate R_{si} and the size of the application D_i. this means that the arrival rate of a SU can be controlled by adjusting these parameters.

System Utilization Model

In the system being discussed, it is clear that the access to channels is totally based on the priorities of SUs. Hence, the availability of channels varies for SUs with different priorities. We understand this through the following discussion. Let SU_1, SU_2 …SUk be the various priority class for the SUs. Let M_1, M_2,…,M_k be the number of SUs that belong to each of the priority class. Then we have M1 > M2 > …> Mk. This means the higher priority SUs have access to more channel resources. The reason for this is the higher priority SUs have access to channels of their priority as well as all the lower priority channels.

Based on this analysis, the server utilization can be defined as

$$\rho_i = \lambda^{eff}_i / (M_i . \mu_i)$$

where M_i is the number of SU in priority class SU_i, μ_i is the system service rate for class SU_i, λ^{eff}_i is the effective arrival rate of a SU. λ^{eff}_i is calculated based on three important conditions which are (i) SU is not blocked, (ii) no false alarm is given on arrival of SU and (iii) packets from this SU priority class are not lost. The effective arrival rate of a SU is thus given by

$$\lambda^{eff}_i = \lambda_i (1 - P^B_i) (1 - P_f) \Pi^S_{j=1} (1 - P^j_{lossi})$$

P^B_i is the probability of SU from classes i being blocked and P^j_{lossi} is the probability of a packet from SU priority class SU_i is not lost.

ALGORITHM

The process of resource optimization is demonstrated by the following algorithm.

Table 1. Optimal Resource Utilization algorithm for CR based SG systems.

For *n* varying from *1 to S*
Determine the parameters R_n, I_k, SI_k, Z_n & SR_k
Compute the resource matrix for SU_n : $R^{m,k}_n$
Compute P_{delay}, P_{loss}, λ^{eff}_n
Obtain ρ_n using the above parameters
Optimize ρ_n as follows:

Input: A vector representing available channels
Function: $\rho_n = \lambda^{eff}_n / M_n . \mu_n$, where *n* is the priority class of the SU.
Output: Optimal CR utilization ρ^{opt}_n

Table 2. Notations

Notation	Meaning
K	No. of channels in spectrum
P	No. of primary users and channels
N	No. of secondary users
S	No. of priority classes of SUs
M	Priority classes of packets within SU
R_n	Resource Matrix
I_k	Interference Matrix for higher priority SU, SU_k
P_T	Probability of using triggered switch
P_s	Probability that a SU switches channels
SI_k	Matrix that represents interference caused by Triggered Switch
P_F	Probability of False Alarm
P_M	Probability of Missed Detection
Z_n	Spectrum Availability Matrix for SU_n
SR_k	Sensing Error matrix of a higher priority SU, SU_k

PERFORMANCE ANALYSIS

The benefits of adopting the optimization algorithm are shown in Fig 2. The figure shows a drastic improvement in system utilization when the optimization scheme is incorporated

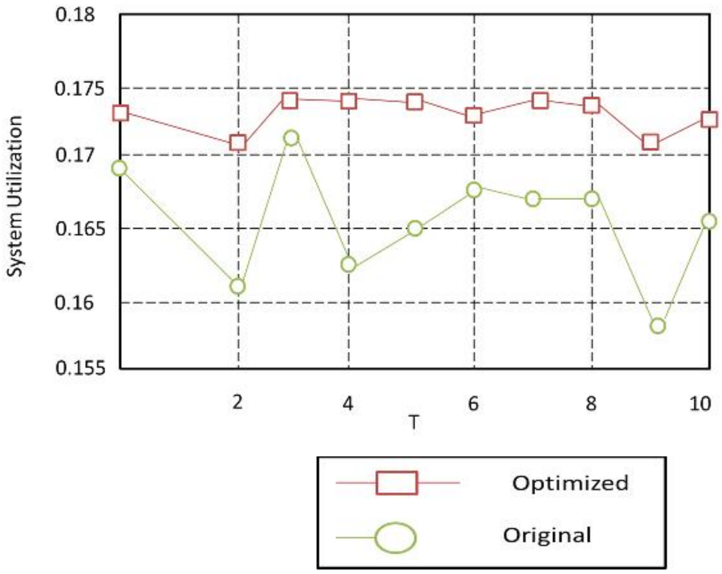

Fig 2. System Utilization before and after optimization

Fig. 3 represents the throughput in the system with priority control and without it. It is very clear from the comparison that with priority control, the throughput in the system is very high. Without priority control, the throughput in the system decreases as it mainly depends on the available channel resources and not traffic density.

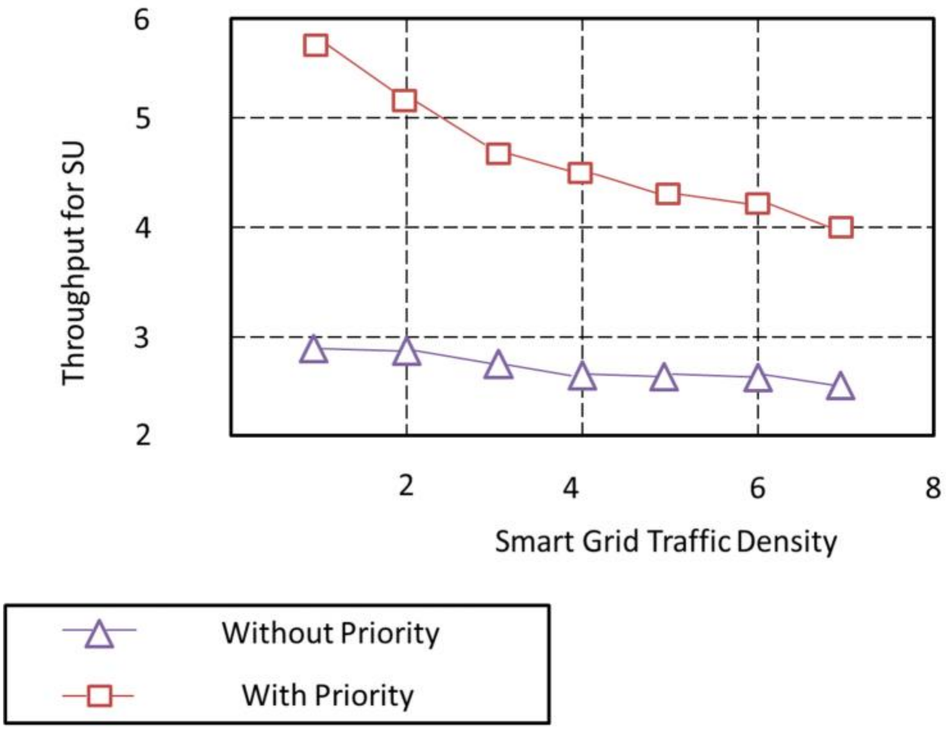

Fig. 3 Throughput comparison with and without priority control

CONCLUSION

This paper has a detailed study on the application of Cognitive radio networks on Smart grid systems. To have an efficient traffic scheduling for the SUs, the various SG traffic types are categorized and assigned unique priorities. In addition, the impact of priority control on CR systems is also studied and the conclusion obtained confirms the fact that CR systems with prioritization are more superior. The proposal gives a performance which is 23% better than the system which doesn't incorporate priority scheduling.

REFERENCES

[1] C. L. N. Ansari, "The progressive smart grid system from both power and communication aspects," *IEEE Commun. Surveys Tuts.*, vol. 14, no. 3, pp. 799–821, 3rd quart., 2012.
[2] Y. Zhang and C. Leung, "A distributed algorithm for resource allocation in OFDM cognitive radio systems," *IEEE Trans. Veh. Technol.*, vol. 60, no. 2, pp. 546–554, Feb. 2011.
[3] Z. M. Fadlullah, M. Fouda, N. Kato, A. Takeuchi, N. Iwasaki, and Y. Nozaki, "Towards intelligent machine-to-Machine communications in smart grid," *IEEE Commun.Mag.*, vol. 49, no. 4, pp. 60–65, Apr. 2011.
[4] J. F.Wan,M. Ghosh, and K. Challapali, "Emerging cognitive radio applications: A survey," *IEEE Commun. Mag.*, vol. 49, no. 3, pp. 74–81, Mar. 2011.
[5] S. Haykin, "Cognitive radio: Brain-empowered wireless communications," *IEEE J. Sel. Areas Commun.*, vol. 23, no. 2, pp. 201–220, Feb. 2005.
[6] R. Puri, A. Majumdar, and P. Ishwar, "Distributed video coding in wireless sensor networks," *IEEE Signal Process. Mag.*, vol. 23, no. 4, pp. 94–106, Jul. 2006.
[7] H. Luo, S. Ci, D. Wu, and H. Tang, "Cross-layer design for real-time video transmission in cognitive wireless networks," in *Proc. INFOCOM IEEE Conf. Comput. Commun. Workshops*, 2010, pp. 1–6.
[8] H. Mansour, J. W. Huang, and V. Krishnamurthy, "Multi-user scalable video transmission control in cognitive radio networks as a markovian dynamic game," in *Proc. 48th IEEE Conf. Decision Control (CDC/CCC 2009)*, pp. 4735–4740.

[9] K. L. A. Y. F. A. G. Tan, P. Komisarczuk, and P. D. Teal, “Exploring new and emerging applications of cognitive radio systems: Preliminary insights and framework,” in *Proc. IEEE Colloq. Humanities, Sci., Eng.(CHUSER)*, Dec. 2011, pp. 153–157.

[10] R. Y.Y. Zhang, S.Gjessing, Y. Chau, S.Xie, andM. Guizani, “Cognitive radio based hierarchical communications infrastructure for smart grid,” *IEEE Network*, vol. 25, no. 5, pp. 6–14, Sep.-Oct. 2011, Special Issue on Commun. Infrastructures for Smart Grid.

[11] R. Puri, A. Majumdar, and P. Ishwar, “Distributed video coding in wireless sensor networks,” *IEEE Signal Process. Mag.*, vol. 23, no. 4, pp. 94–106, Jul. 2006.

[12] M. Erol-Kantarci and H. T.Mouftah, “Wireless multimedia sensor and actor networks for the next-generation power grid,” *Ad Hoc Networks*, vol. 9, no. 4, pp. 542–551, Jun. 2011.

[13] D. Niyato and E. Hossain, “Cognitive radio for next-generation wireless networks: An approach to opportunistic channel selection in IEEE 802.11-based wireless mesh,” *IEEE Wireless Commun.*, vol. 16, no. 1, pp. 46–54, 2009.

[14] Q. Qu, L. B. Milstein, and D. R. Vaman, “Cognitive radio based multiuser resource allocation in mobile ad hoc networks using multi-carrier CDMA modulation,” *IEEE J. Sel. Areas Commun.*, vol. 26, no. 1, pp. 70–82, Jan. 2008.

[15] V. C. Gungor, B. Lu, and G. P. Hancke, “Opportunities and challenges of wireless sensor networks in smart grid,” *IEEE Trans. Ind. Electron.*, vol. 57, no. 10, pp. 3557–3564, Oct. 2010.