Satellite Cognitive Communications and Spectrum Regulation

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SUMMARY

Due to rapid increase of wireless users and the popularity of multimedia applications, the demand for wireless spectrum is increasing rapidly. However, due to current static spectrum policy, the available usable spectrum is becoming scarce while a significant amount of spectrum remains underutilized. In this aspect, cognitive communications can be considered as a promising technology to enhance spectrum usage efficiency by allowing the coexistence of heterogeneous networks within the same spectrum. In this paper, starting with the rationale of cognitive communication, we present two different coexistence scenarios in the context of satellite cognitive communication. We then present the current status of spectrum regulation in the context of Cognitive Radio (CR) and the relevant decisions of World Radio Conference 2012 (WRC-12). Finally, we present the technical aspects and regulatory challenges of this technology and provide some suggestions from research, industrial and regulatory perspectives.

I. INTRODUCTION

The demand for broadband services is increasing constantly driven by various applications in areas such as business, education and entertainment. The increasing demand for high speed wireless internet as well as digitized audio and video is leading to a rapidly expanding market for wireless multimedia services. However, the available spectrum is becoming scarce due to the spectrum segmentation and the dedicated frequency allocation of the standardized wireless systems. Currently, different chunks of spectrum are allocated to different geographic regions as well as to different operators within the same country. Because of the increase in spectrum demand, current static allocation policy faces spectrum scarcity while a significant amount of spectrum remains underutilized for almost 90% of time [1]. The Federal Communication Commission (FCC) measurements have indicated that many licensed frequency bands remain unused nearly for ninety percent of time [1]. Moreover, from the survey of worldwide spectrum occupancy measurement campaigns at different locations carried out in [2], the average spectrum occupancy rate has been found to be very low and it shows the temporal as well as spatial variations. As user demands for data services and data rates increase rapidly, efficient spectrum usage is becoming a critical issue. FCC has recently launched a secondary markets initiative with the aim of removing the regulatory barriers and promoting the development of secondary markets in spectrum usage rights among the wireless service providers [3].

Current wireless networks are characterized by a static spectrum allocation mechanism in which international ITU-R bodies assign frequency bands to the license holders on a long-term basis for different geographical regions. With regard to satellite communication, fixed satellite services use C and K band frequencies and for mobile satellite services, L and S frequency bands are better suited due to better foliage penetration and less impact of atmospheric affects. Due to high demand of broadband services and limited availability of L and S-band frequency resources, higher frequency bands i.e. Ku and Ka bands have also been assigned for mobile satellite services. At present, Ku band based mobile satellite services are available to provide broadband services in many mobile users such as trains, boats, planes, and cars [4]. There has been continued pressure on satellite bands, especially in L and C bands due to the introduction of new terrestrial services such as 3G mobile telephony, LTE, WiMax and WiFi services [4].

Static allocation of the frequency spectrum in a traditional way does not meet the requirements of future wireless technologies. Technical developments such as software defined radio, wideband transceivers, increased computation power etc. have led to the advent of Cognitive Radio (CR) and the possibility of utilizing the spectrum in a very dynamic and adaptive manner.. In this direction, cognitive communication can be considered as a potential technology to enhance the spectrum usage significantly in the context of hybrid networks and CR plays a vital role in cognitive communication as it is aware of its operating environments and can adjust its radio interface dynamically [6]. Furthermore, there is significant amount of spectrum available for the future development of satellite cognitive communication due to very low average occupancy of the allocated spectrum for different satellite services [2,5]. To facilitate the implementation of this technology, regulations need to adapt accordingly.

Satellite communication plays a vital role in wireless communication field due to its wide area coverage, higher speed and ability of providing new services with different characteristics than those of terrestrial networks. It allows the extension of the coverage area of services today carried on terrestrial, mobile and fixed networks. Moreover, satellite technology has made it economically feasible to bring broadband communications to sparsely populated remote regions improving the access to medical services, education, e-government and other services that are expensive to provide by other means. In small rural communities, it is very costly and difficult to deploy terrestrial networks. In this context, satellite communication has played an important role to bridge the digital gap in the rural communities and for economic and social development in these regions. Satellite communication is the only viable option for many services in a vast range of sectors such as land mobile, aeronautical, maritime, transports, military, rescue and disaster relief etc. Furthermore, satellite communication plays significant roles in supporting hybrid satellite/wired or satellite/wireless infrastructures. Hybrid networks may exist in the same spectrum in different ways such as two terrestrial networks or two satellite networks or satellite-terrestrial networks.

The remainder of this paper is organized as follows: Section II presents two different coexistence scenarios in the context of satellite cognitive communication and provides the benefits and challenges of satellite CR. Section III describes the different aspects of spectrum regulation along with the current regulation status and WRC-12's decisions for the CR. Section IV presents the regulatory challenges and provides some roadmaps for the practical implementation of satellite cognitive technology. Section V concludes the paper.

II. COGNITIVE SATCOMS

In cognitive communication terminology, Primary Users (PUs) can be defined as the users who have higher priority or legacy rights on the usage of a specific part of the spectrum. On the other hand, Secondary Users (SUs), which have lower priority, exploit this spectrum in such a way that they do not cause harmful interference to the operation of PUs [7]. SUs need to have CR capabilities, such as Spectrum Sensing (SS) to check whether it is being used by a PU and to adapt the radio parameters to exploit the unused part of the spectrum. CR can sense the spectrum usage and detect the idle frequency bands, then these bands can be allocated to SUs when PUs do not use these bands in order to avoid any interference caused by SUs to the PU. This can be done in a highly dynamic manner. The most common cognitive techniques in literature can be categorized into interweave or SS, underlay, overlay and database related techniques. The possible frequency bands along with the primary/secondary systems and system types are shown in Table I. In SS only techniques, SUs are allowed to transmit whenever PUs do not use that specific band, whereas in underlay techniques, SUs are allowed to transmit as long as they meet the interference constraint of PUs. Most CR research has focused on terrestrial part and the use of cognitive technique in satellite communication has received less attention. It may be argued that the satellite link should be given priority due to adverse transmission characteristics of the satellite link. Depending on the geographical location and interference power level, suitable cognitive techniques can be selected. The ground interference received by the satellite terminal depends on its elevation angle and the elevation angle differs for different geographic locations with its value decreasing towards the north [8]. In cognitive SatComs scenario, polarization and angle dimension can be considered as additional degrees of freedom [9, 10]. If a primary terrestrial/satellite system operates in one type of polarization e.g. H/V or RHCP/LHCP, the secondary satellite/terrestrial system can be operated in the same spectrum using another nature of polarization. Similarly, primary and secondary systems can coexist within the same spectrum using separate radiation patterns in such a way that secondary antenna pattern does not interfere the operation of PUs. In the following subsections, we provide two coexistence scenarios in the context of Cognitive SatComs.

Table I. Possible Frequency bands for cognitive coexistence of hybrid networks

Freq. Band	Link	Freq. Range	Primary	Secondary	System Type
S	Uplink	2.17-2.20	Sat/Terr	Sat/Terr	Vehicular, Sensor Networks, Handheld
S	Uplink	1.98-2.01	Sat	Terr	Vehicular, Sensor Networks, Handheld
C	Uplink	3.4-3.8	Terr	Sat	Fixed, Nomadic, Vehicular
Ku	Uplink	13.75-14.5	Sat1	Sat2	Fixed, Nomadic
Ku	Downlink	10.7-12.75	Sat1	Sat2	Fixed, Nomadic
Ka	Uplink	27.5-29.5	Terr/Sat	Sat	Fixed, Nomadic, Maritime, Aeronautical, Interactive TV
Ka	Downlink	17.7-19.7	Sat	Terr/Sat	Fixed
Ka	Downlink	17.3-17.7	[1]BSS Feeder	[2]HDFSS	Fixed

A. Coexistence Scenarios

Figure 1 shows the hybrid satellite-terrestrial network with different modes of operation. This hybrid network may work in forward normal mode, forward reverse mode, return normal mode and return reverse mode as shown in the figure. It comprises two communication links sharing the spectrum: i) satellite to satellite user terminal, ii) terrestrial Base Station (BS) to terrestrial user terminal. In this context, two priority conditions can be set i.e. by providing primary access to the satellite or to the terrestrial network. An important application for this scenario can be satellite network operating in C band and terrestrial WiMax networks. Another scenario for this network architecture can be the exploitation of the VHF analog spectrum which is available after the switchover to DVB-T. This spectrum can be shared by a satellite to vehicle service and a terrestrial mobile network using suitable cognitive techniques.

Figure 2 shows the dual satellite coexistence scenario in which two satellites owned by two different operators are connected to different gateways on the Earth. These satellites are assumed to be fixed equipped with multibeam antennas and provide coverage to the same geographic region in the Ka band. One of these two satellites can work as primary user and another as secondary user. It can be assumed that the coverage area of two satellites can be overlapping but their multibeam patterns are not identical. The frequency reuse concept can be used in cellular planning of both satellites to increase the capacity. The concept which can be applied in such a scenario is that the frequencies which are used in one satellite are not repeated in the frequency planning of other satellites. The primary system shares its frequency plan to the secondary

[1] Broadcasting Satellite Service
[2] High Density applications in the Fixed Satellite Service

system, forming a way of cognition between them. Alternatively, secondary users comparatively sense the primary frequency plan and report back to the secondary gateway. The cognition link can be established on the ground by using a backhaul link feeding the cognitive information from primary ground station to the secondary ground station. The secondary operator sets its frequency plan based on primary operator's frequency plan so that the frequencies will not be repeated. In this way, effective utilization of spectrum can be obtained by forming cognition between primary and secondary operators. Using proper scheduling techniques, both operators can provide service with limited interference.

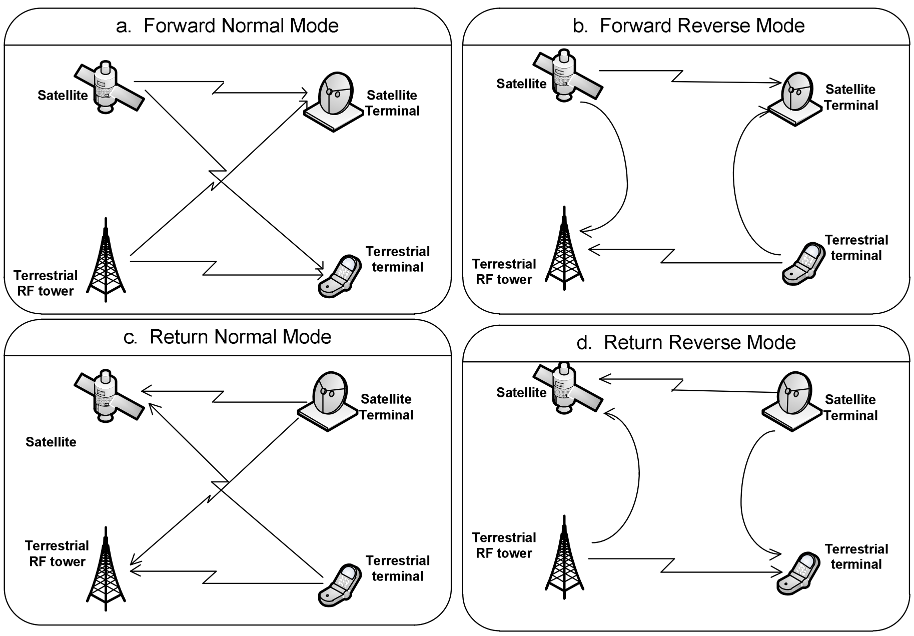

Fig. 1. Different Modes in Satellite Terrestrial Scenario

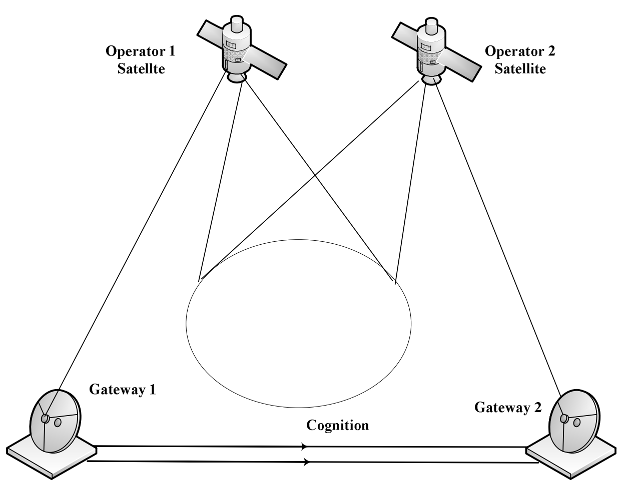

Fig. 2. Two Satellite Coexistence Scenario

B. Benefits and Challenges

Cognitive SatComs technology can provide several advantages to industries, operators and consumers. From the global perspective, the overall efficiency of spectrum usage can be increased. From an industrial point of view, a mobile market can be revitalized by the advent of a new CR equipment market and there may occur a high level of competition with low entry barriers. Furthermore, from an operator's perspective, it can create new revenue streams from secondary trading as well as can improve the utilization of the spectrum resource that they already own. Moreover, consumers can subscribe a personalized and optimized mobile and broadband data service at low cost.

Besides several advantages of cognitive SatComs, there are several challenges from the perspectives of business, technical and regulatory sectors which need to be addressed for the practical implementation of this technology. In the current spectrum market, there exists no cooperation between satellite and terrestrial operators. Cooperation at the international as well as at the national level is extremely important to implement this technology. In addition, incorporating satellite receivers into the terrestrial terminals may increase the complexity and cost due to requirement of additional hardware. Furthermore, business models and standards for spectrum sharing between satellite and terrestrial operators are not developed. In addition to the business challenges mentioned above, there exist several technical challenges. Satellite communication is characterized by limited power and wide-area coverage which makes implementation of dynamic spectrum sensing in the forward link difficult. Moreover, effective intersystem and intersystem interference mitigation techniques need to be investigated and Quality of Service (QoS) management, mobility and security aspects should be addressed properly. Developing technical standards for satellite cognitive scenario is also another challenge to be addressed.

In addition to these business and technical aspects, regulatory aspects also play major role in the implementation of this technology. In the following sections, we present the discussion and issues related to spectrum regulation in the context of cognitive SatComs.

III. SPECTRUM REGULATION

Radio frequency spectrum is a limited natural resource and it does not respect the international geographical boundaries. Furthermore, it is not consumed upon its usage unlike other natural resources and it is liable to be wasted if it is not used optimally and efficiently. There are following two important principles of radio communications. i) Radio transceivers must use the same frequency to communicate effectively, ii) Cochannel interference typically occurs if two or more radio transceivers operate at the same frequency, within the same geographical area, at the same time and the quality of the communication is reduced. Therefore, spectrum usage must be shared among the various radio services and it must respect the provisions of national and international regulations. In addition, acceptable QoS should be provided to all the radio terminals and radio terminals should not be blocked from spectrum access and transmission for extended durations. The following two types of problems may arise while concerning about the spectrum regulations. The tragedy of commons problem results due to overuse of spectrum due to missing regulation while the tragedy of anticommons results in inefficient spectrum utilization due to too restrictive regulation. In this context, the regulations help to control the estimation parameters such as transmit power and interference i.e. out of band transmissions within the acceptable limit to have the proper coexistence of different systems within the same spectrum. The regulations are required to ensure that the cost of CR terminals in the market is not increased beyond some prescribed limit which is set based on the affordable capacity of average customers.

The current spectrum allocation process operates at both national and international levels. At the international level, International Telecommunication Union (ITU), a specialized agency of the United Nations, is responsible for spectrum management. International bodies tend to set out high level guidance which national bodies adhere to in setting more detailed policy. International coordination is essential in the cases where the zones of possible interference extend beyond national geographical boundaries and users are inherently international such as maritime and aviation. Regional bodies such as CEPT, EC and ETSI are responsible for making decisions, preparing reports, recommendations, directives and harmonized standards in the regional level. At national level, each administration has its own regulating agency like NTIA/FCC in USA, Ofcom in UK.

In most of the current primary only systems, international ITU-R bodies assign fixed spectrum bands to license holders on a long-term basis for large geographical regions. In these systems, the spectrum remains idle for most of the time when the services are not active and the spectrum is not utilized effectively. The exclusive spectrum usage rights are mostly implemented through transmission power caps and guard bands, which are determined by the regulators [11]. Without these two aspects, it is difficult to prevent out of band and in-band interferences. For enhancing the spectrum usage among different networks, the spectrum ownership can be transferred from spectrum owner to another party for a short time. There exist the following different forms of spectrum ownership [12]. i) The usage rights can be assigned to another party for short/medium term with a total transfer of rights and duties, ii) Short term spectrum leasing based on traffic variations, whereby the rights and duties may still remain with the main usage right holders., iii) Spectrum trading, whereby the rights and duties also may still remain with the main usage rights holders, and iv) Spectrum pooling which can occur as pure pooling as well as hybrid pooling (i.e. fixed bands plus shared pool). Assigning ownership in spectrum pooling technique is a challenge for the regulators.

A. Current Regulation Status for CR

In this subsection, we present the current regulation status for CR from spectrum sharing perspectives. Regarding change in ownership, temporal short term change of usage right is possible. However, current administrative process is time consuming and an automated real-time system is needed. Regarding spectrum leasing and trading, no implications can be noted since original licensee is liable for any interference/misuse. In addition, no clear assignment of ownership can be done for spectrum pooling. With regard to the change in technology, most licensee define the BEM (Block Edge Mask) in which transmission signal must remain independent of the technology used. Furthermore, considering the change in transmission characteristics, any transmission characteristics are permitted as long as the BEM criteria is not violated. Moreover, with regard to the requirement of additional Radio resources, many investigations have suggested the need of Cognitive Pilot Channel (CPC) and it is widely discussed in regulatory bodies. Spectrum databases and trading are the current prominent techniques and these techniques can be considered as the possible first steps towards the implementation of dynamic spectrum access techniques. Spectrum trading is an important mechanism to increase the overall spectrum utilization and to open up business opportunities to get access to desired spectrum [11]. Regulatory rules for spectrum trading have been implemented in some countries for some bands, for example in UK [14] and US [15]. Database approach has been widely discussed in CR community in the context of TV whitespaces for enhancing the usage of licensed spectrum. By implementing a database approach, the radios can take the first step towards efficiently utilizing the idle spectrum at any given point in time [16]. This approach could work essentially for all spectrum bands instead of only TV whitespace bands, enabling priority driven, lease-based access to maximize the spectrum usage efficiency. Some of the standards in the context of terrestrial CR have been listed in the following subsection [17]. There are currently no standards in the context of cognitive SatComs.

B. Standards for Terrestrial CR

1. IEEE 1900 Family: This family includes the standard definitions and concepts for spectrum management and advanced radio system technologies, recommended practice for interference and coexistence analysis, spectrum access behavior of radio systems employing dynamic spectrum access methods and other standards for optimized radio resource usage in heterogeneous wireless access networks, procedure for exchanging spectrum sharing information etc.

2. IEEE 802.11 af and IEEE 802.22: These standards define the technologies for cognitive radio over TV white space.

3. LTE Femtocells: Long Term Evolution (LTE) Femtocells include the functionality of searching for a radio channel and estimating which resources are free among the available ones in order to avoid the interference.

4. LTE SON: LTE Self Organizing Networks (SON) is an approach of cognitive radio aspects from cellular networks perspective.

5. IEEE 802.16m (4G): This standard has the functionality to reuse/share bandwidth with legacy systems.
6. LTE advanced (4G): LTE advanced is a 4G standard and it has spectrum flexibility for the support of scalable bandwidth and spectrum aggregation.

C. WRC-12's Decision for CR

The World Radio Conference (WRC) is a supreme body in worldwide management and regulation of the radio frequency spectrum. This body is authorized to revise ITU radio regulations and the revisions are made on the basis of an agenda established in previous WRC. Different study groups, working parties consider technical aspects of the agenda items for WRCs. It is held normally every four years. WRC-2012 was held in Geneva from 23 January to 17 February 2012. The main functions of WRC are to revise the radio regulations and any associated frequency assignment and allotment plans, to address any radio communication matter of worldwide character, to instruct the radio regulation Board and the radio communication Bureau and review their activities, to determine questions for study by the Radio Communication Assembly (RA) and its study groups in preparation for future WRCs. A list of relevant topics is presented below [12].

Resolution 956 (WRC-07): Regulatory measures and their relevance to enable the introduction of software-defined radio and Cognitive Radio Systems (CRS).

Agenda Item No. 1.19 (WRC-12): To consider regulatory measures and their relevance, in order to enable the introduction of software-defined radio and CRS, based on the result of ITU-R studies, in accordance with Resolution 956 (WRC-07).

Decision (WRC-12): The agenda item no. 1.19 was suppressed (No further Study) considering that no need for modification to the radio regulations.

Recommendation COM6/1 (WRC-12): Deployment and use of CRS: Recognizing that (i) any radio system implementing CRS technology needs to operate in accordance with the provisions of the radio regulations, (ii) the use of CRS does not exempt administrations from their obligations with regard to the protection of stations of other administrations operating in accordance with the radio regulations, and (iii) CRSs are expected to provide flexibility and improved efficiency to overall spectrum use, recommends that administrations participate actively in the ITU-R studies conducted under Resolution ITU-R 58, taking into the account of first two points [13].

IV. REGULATORY CHALLENGES AND ROADMAP

Satellite CR faces several business, technical and regulatory challenges for its proper practical implementation. Herein, we present some of the important regulatory challenges. Due to lack of proper regulations to facilitate sharing/trading for all spectrum bands, difficulty arises in implementing sharing/trading spectrum business. In this context, regulators should specify the threshold values for Effective Isotropic Radiated Power (EIRP) and out of band interference limits for proper operation of cognitive SatComs. Furthermore, the secondary dynamic access mechanism to government/military exclusive spectrum should be properly addressed in terms of regulations since the instant release is required when spectrum is needed in public safety and emergency scenarios. Moreover, there should be sufficient level of interaction between national and international authorities. The collaboration between the authorities at the national level is required for the management of terrestrial spectrum while the collaboration at the international level is needed for the management of satellite spectrum. The agreement at the ITU-R level about the regulatory requirements of satellite cognitive systems is necessary.

There should be sufficient interaction between technology, market and the policy to implement satellite CR. Research efforts should be directed towards investigating new techniques to allow the coexistence of different networks as well as analyzing the performance of satellite CR systems. The technological solutions should be then standardized by respecting the spectrum regulations. Furthermore, the industries should come up with viable business models by collaborating with the research institutions and they should work towards manufacturing affordable CR equipment by analyzing the market situation. Moreover, the regulators should ensure the regulation of flexible spectrum ownership properly and they should recommend different parameters such as interference threshold to ensure that new systems do not affect the operation of the previously deployed systems.

To facilitate the research and implementation of satellite cognitive networks, Interdisciplinary Centre for Security, Reliability and Trust (SnT) research center of University of Luxembourg is carrying out two research projects, CO2SAT (“Cooperative and Cognitive Architectures for Satellite Networks”) and CORASAT (“Cognitive Radio for Satellite Communications”). The CO2SAT project has SES, one of the world leading satellite operators, as its advisory partner. The objective of CO2SAT project is to evaluate the performance gain of cooperative and cognitive radio networks in comparison to the traditional satellite systems and to investigate new techniques for satellite networks towards higher throughput and energy efficiency. The CORASAT project is a European Union project under a FP7 grant and SnT is one of the 6th partners in this project. This project aims at investigating, developing and demonstrating cognitive radio techniques in satellite communication systems to facilitate the spectrum sharing. The outcome of this project is expected to produce strategic roadmaps to be followed by industry stakeholders, European institutions and government actors towards the regulatory and standardization groups so that necessary actions will be undertaken to open new business perspectives for Cognitive SatComs in the support of digital agenda for Europe.

V. CONCLUSION

Cognitive communication is a promising technology for the coexistence of different networks in the same spectrum. In this paper, starting with the importance of satellite cognitive technology for enhancing the spectrum usage efficiency, we present two coexistence scenarios and present the benefits and challenges of this technology. We further present the regulation aspects of CR and relevant decisions of WRC-12 for the CR. There exist several business, technical and regulatory challenges for practical deployment of satellite cognitive systems. If technology, market and policy are adapted to the requirements of this technology properly, the spectrum scarcity problem can be addressed by deploying the cognitive radio systems.

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BIOGRAPHY

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He has held research positions at the Department of Electrical Engineering, Linköping University; the Information Systems Laboratory, Stanford University, Stanford, CA; and the Katholieke Universiteit Leuven, Leuven, Belgium. In 1991, he was appointed Professor of signal processing at the Royal Institute of Technology (KTH), Stockholm, where he was head of the Department for Signals, Sensors and Systems from 1992 to 2004 and Dean of the school of Electrical Engineering from 2004 to 2008. Since 2009, he has been Director of Interdisciplinary Centre for Security, Reliability and Trust (securityandtrust.lu) at the University of Luxembourg. During 1996-1997, he was Director of Research at ArrayComm Inc. San Jose, CA; a start-up company based on Ottersten's patented technology. His research interests include wireless communications, stochastic signal processing, sensor array processing, and time-series analysis.

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