Wireless Communications: Trends and Challenges

Kapila C. Wavegedara, Gaurav Bansal, Praveen Kaligineedi, Majid Kabbazian,
Ashok K. Karomokar, Mamunur Rashid, Hugues Mercier and Vijay K. Bhargava
Department of Electrical and Computer Engineering,
University of British Columbia, 2356 Main Mall
Vancouver BC V6T 1Z4, Canada
Email: {kapilaw, vijayb}@ece.ubc.ca

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***Abstract*— Emerging demands for high data rate services and high spectral efficiency are the key driving forces for the continued technology evolution in wireless communications. Third generation (3G) mobile communication systems have already been commercially deployed in certain parts of the world to meet the initial demand for high data rate packet-based services including wireless internet access. Recently, several advancements have been introduced for 3G wireless systems to further enhance the data rate and the system performance (e.g., high speed downlink packet access (HSDPA) in wideband code division multiple access (WCDMA) systems, 1x evolution-data and voice (1xEV-DV) in cdma2000 systems). Nevertheless, due to rapid growth of wireless multimedia services, it is apparent that 3G wireless systems will be unable to comply with the ever increasing demand for broadband wireless services. As a result, even before widespread commercial deployment of 3G wireless systems, the standardization process of the next generation wireless communication systems (namely, fourth generation (4G) or beyond 3G (B3G) systems) has already been initiated. The next generation broadband wireless systems are expected to support variety of services requiring different data rates and different QoS (quality of service) levels. Obviously, the key feature of 4G (or B3G) systems over growing 3G systems is the feasibility of much higher data rate services. In this paper, an overview of leading technological advances that enable broadband wireless capabilities and state-of-the-art research in various aspects of wireless communication is presented. The topics include multiple-input multiple-output (MIMO) systems, cooperative diversity, ultra wideband (UWB), cross-layer design, QoS provisioning, cognitive radio and wireless security.**

I. Introduction

Ever increasing demands for high data rate packet-based services and high spectral efficiency are the main driving forces for the continued evolution of wireless communications technology. Although second generation (2G) wireless communication systems (e.g., GSM, IS-95) were highly successful in the last decade, they have very limited capabilities of supporting high data rate packet-based services. As a result, third generation (3G) wireless communication systems have been developed and standardized in the late 90's. 3G systems are capable of offering much higher data rates than 2G systems. The minimum data rates supported in wideband code division multiple access (WCDMA) systems in different communication environments: 144 kbit/s for high mobility (vehicular) traffic, 384 kbit/s for pedestrian traffic and 2 Mbit/s for indoor traffic [1]. There are three main radio interface standards proposed for 3G: WCDMA based on direct spread (DS)-CDMA with frequency division duplex (FDD), cdma2000 based on multicarrier-CDMA and TDD (time division duplex)-CDMA [2]. 3G wireless systems have already been commercially deployed in certain parts of the word (e.g., in Japan, North America).

Recently, several enhancements have been introduced into the 3G cellular wireless standards to further increase the data rate and to improve the system performance, e.g., high speed downlink packet access (HSDPA) for WCDMA systems, 1x evolution-data and voice (1xEV-DV) in cdma2000 systems. HSDPA is a packet-based data service technology that increases the data rate up to 8-10 Mbit/s (and up to 20 Mbit/s for MIMO systems) in the downlink of W-CDMA. HSDPA standards incorporate recent technological advances in wireless communications such as adaptive modulation and coding (AMC), multiple-input multiple-output (MIMO) and hybrid automatic request (HARQ) [3]. In cdma2000 systems, 1xEV-DV standard provides downlink data rates up to 3.1 Mbit/s and uplink data rates of up to 1.8 Mbit/s [2], [4].

During the recent years, in parallel with the evolution in cellular mobile communications, a rapid development has been observed in wireless local area networks (WLANs). WLAN connects various mobile devices (e.g., laptops) within a building or a campus area without using cables. A typical WLAN consists of cabled backbone network with wireless access points connecting the wireless devices to the wired network. Working group 11 of IEEE LAN/Metropolitan Area Network (MAN) standards committee (IEEE 802) developed a set of standards for Wireless LAN. Wi-Fi Alliance is an organization which certifies all WLAN products based on 802.11 standards for interoperability. The products which pass Wi-Fi Alliance testing are referred to as ”Wi-Fi certified”. However, the term Wi-Fi has become synonymous with IEEE 802.11a/b/g standards. Wi-Fi is a global set of standards. Hence, Wi-Fi products can operate all over the world. Wi-Fi products use unlicensed spectrum in 2.4 GHz (802.11b/g standards) and 5 GHz (802.11a standard) radio bands. 802.11a standard is based on orthogonal frequency division multiplexing (OFDM) and achieves maximum data rate of 54Mbps. 802.11b standard is based on direct sequence spread spectrum (DSSS) and achieves maximum data rate of 11Mbps. Since 802.11a and

802.11b operate in different bands, they are not compatible with each other. To get around this problem, 802.11g standard was developed to maintain compatibility with 802.11b and also attain the high data rates of 802.11a. 802.11g standard uses both OFDM as well as DSSS modulation schemes. Both 802.11b and 802.11g suffer from interference from other Wi-Fi devices and non Wi-Fi devices operating in 2.4 GHz unlicensed spectrum such as cordless telephones and microwave ovens. 802.11a which operates in 5 GHz unlicensed spectrum has lesser interference but suffers from smaller range because of the high carrier frequency. In the future, Wi-Fi is likely to adopt MIMO technology [5].

The bandwidth provided by the existing 2.5G or evolving 3G wireless systems is sufficient for basic internet access and multimedia based services (low data rate). In the recent years, a rapid growth has been noticed in the demand for high data rate services mainly due to the development of new services and applications provided by the internet and the emergence of new multimedia services such as live video transmission, interactive video games and video conference. Hence, it is apparent that existing 2.5G or evolving 3G wireless systems will be unable to comply with this emerging demand for broadband wireless services [6]. As a consequence, even before widespread deployment of 3G wireless systems, the standardization process of the next generation wireless communication systems (namely, fourth generation (4G) or beyond 3G (B3G) systems) has already commenced.

The next generation broadband wireless systems are expected to support variety of services requiring different data rates and different quality of service (QoS) levels. Obviously, the key feature of 4G (or B3G) systems over existing 2.5 systems and evolving 3G systems is the feasibility of much higher data rate services (up to 100 Mbit/s in outdoor communication environments and up to 1 Gbit/s in indoor communication environments) [1]. The major technical challenges in the physical layer will be to achieve high spectral efficiency ($\approx$ 10 bit/Hz/s) and to handle severe frequency-selectivity due to use of large bandwidths [7]. The use of multiple transmit and receive antennas to achieve high spectral efficiency will probably be a feature of future wireless systems. In addition to enhancements in the physical layer, the advancements in higher layers will, of course, be mandatory. Provisioning of end-to-end QoS for different multimedia services is challenging due to heterogeneities in the wireless networks and also due to difficulties in handling internet protocol (IP) based multimedia services in wireless mobile environments [6]. Another major challenge will arise in the seamless integration of heterogeneous networks; non-IP based wireless systems (e.g., 3G-WCDMA) and IP-based systems (e.g., WLAN based on IEEE 802.11a). The always best connected (ABC) capability will be an interesting feature of the next generation wireless systems. ABC technology will allow users to connect the wireless network through best available devices and access technology (see [8] for details).

In this paper, we present the overview of the leading wireless technological advances that enable broadband wireless capabilities and state-of-the-art research in various aspects of wireless communication.

II. Advances in Physical Layer

In the next generation wireless communication systems, major research challenges in facilitating broadband service with high spectral efficiency may lie in the physical layer. Hence, it has become crucial to incorporate the recent technical advances in the physical layer into the future wireless systems. Multiple-input multiple-output (MIMO) is a promising technology to improve the wireless system capacity and in the past few years, a lot of research has been carried out in various aspects of MIMO systems. Space-time (ST) coding has evolved as an effective transmit diversity technique to achieve high performance over fading wireless channels. Hence, ST coding based transmit diversity (STTD) has already been included in 3G wireless communication standards (e.g., WCDMA systems). Cooperative diversity has recently emerged as a very popular technique to achieve an additional diversity gain to combat the effects of severe channel fading. In contrast to conventional point-to-point communication, in cooperative diversity systems, the cooperative users will share the resources (e.g., time, frequency) and each cooperative user transmit not only his own information, but also the information of other users. It is of great importance to develop a multiple access scheme that can efficiently serve a large number of users with high data rates simultaneously. Multicarrier CDMA has recently attracted significant attention as a promising multiple access scheme for future broadband wireless systems. Emerging technologies such as software defined radio (and cognitive radio) have received increasing interest and these technologies can be effectively used to further improve the spectral efficiency through the proper management of the allocated spectrum.

A. Multiple-Input Multiple-Output (MIMO) Communications

In wireless communications, when multiple antennas are employed at both the transmitter and the receiver, such a system is commonly known as a multiple-input multiple-output (MIMO) system. MIMO techniques can be effectively used to increase system throughput over hostile wireless channels. It is wellknown fact that with the number of transmit antennas N_T and number of receive antennas N_R, the capacity of MIMO systems increases linearly with $N_T N_R$. During fast few years, MIMO communications have received a tremendous interest in the literature. MIMO is considered to be as an extension of conventional smart antenna systems (SASs). In SASs, beamforming techniques are used and the optimal antenna weighting vector that determines antenna radiation pattern is computed based on the optimal criterion such as maximum signal-to-interference plus noise ratio (SINR), minimum mean square error (MMSE) (see [9] for a good overview of SASs). Conversely, in MIMO systems, beamforming is not adopted. The ability to exploit multipath propagation can be considered as one of the advantages of MIMO systems. In contrast to transmit bemaforming schemes, channel state information (CSI) is generally not required at the transmitter of MIMO systems. Transmission techniques developed for MIMO systems can be coarsely classified into two broad categories: spatial multiplexing and space-time (ST) coding. In spatial multiplexing based MIMO schemes, it is attempted to maximize the data rate or the throughput over MIMO channel, whereas in the second approach, it is attempted to maximize the diversity gain through ST coding [10].

In spatial multiplexing-based MIMO transmission, independent data streams are transmitted through each transmit antenna to yield spatial multiplexing gain. Each data stream is separated at the receiver typically using a multisuer interference cancelation-based detection scheme. A spatial multiplexing scheme, referred to as diagonal-Bell labs layered space-time (D-BLAST) architecture, was introduced by Foschini in [13]. Later, a more computationally efficient scheme for the BLAST architecture known as vertical-BLAST (V-BLAST) was proposed in [11]. In [12], a Turbo-BLAST scheme, which combines the BLAST and Turbo or iterative detection principles has been developed. Recently, due to advantages of both MIMO and orthogonal frequency division multiplexing (OFDM), the combination of MIMO and OFDM (MIMO-OFDM) for broadband transmission has become a popular research area (good overview found in e.g., [14], [15]).

On the other hand, in space-time (ST) coded systems, multiple redundant streams are transmitted through multiple transmit antennas to achieve the diversity gain to mitigate the effect of channel fading. In this case, it is not necessary to have multiple antennas at the receiver (note that when only the transmitter employs multiple antennas, a such system is usually referred to as a multiple-input single-output (MISO) system). ST codes were originally proposed and investigated for frequency-flat (FF) fading channels (ST trellis codes e.g., [16], ST block codes e.g., [17], [18]). Low decoding complexity of ST block codes has made them more attractive compared with ST trellis codes. In broadband communication, wireless channels become frequency-selective (FS) and channel equalization is indispensable to mitigate the detrimental effects of the inter-symbol interference. On the other hand, OFDM convert the FS channel into a set of FF fading subchannels. Hence, ST codes designed for FF fading channels can be simply adopted with OFDM for FS channels. Design of space-time frequency codes for OFDM systems is still an active research area (see [15] and references therein). Block-transmission based ST block coding schemes for FS fading channels have been investigated in [19]. On the other hand, direct application of (symbol-wise) Alamouti ST block code in FS channels is considered in [20] and references therein.

During the last few years, there had been lot of research on ST coding for FF fading channels. Nevertheless, research on ST coding for FS channels received relatively limited attention. Development of novel ST block coding schemes for FS channels, which facilitate simple ST decoding and equalization at the receiver, can be considered as a still open and challenging research topic. Further investigation on efficient equalization schemes for ST block coded transmission (for both symbol-based and burst-based schemes) will be needed. Investigation of concatenation schemes of ST coding and channel coding for multipath fading channels with low-complexity Turbo (iterative) receiver processing will also be an interesting research topic. Channel estimation in MIMO systems may be much more difficult compared with SISO systems. Hence, the development of efficient channel estimation schemes for single-carrier MIMO systems in multipath fading and MIMO-OFDM systems under fast time-varying environments will be another research challenge. Moreover, when the channel state information (CSI) is available at the transmitter, antenna power allocation can be optimized compared to the conventional equal power allocation. Hence, efficient feedback of CI from the receiver to the transmitter will also be needed to address [10]. On the other hand, there are several practical issues, such as implementation of multiple antennas and integration of MIMO techniques to existing wireless systems, to be addressed in the future before commercial deployment of MIMO techniques (see e.g., [10] for more details).

B. *Cooperative Diversity*

Future generation wireless communication will have to meet the demands of high data rate packet-based services and hence, it will have to employ advanced techniques. The wireless channel suffers from a severe channel impairment known as fading and for combating fading, diversity is of great importance. In a recent work in [21], [22], a new method called cooperative communications has been proposed, in which diversity gains are achieved by the cooperation of mobile users. Each user is responsible for not only transmitting their own data, but also act as a cooperative agent (transmit data for other users). It has been shown in [21], that by using cooperative communications, achievable rate region improves significantly for the same transmit power. Hence, spectral efficiency can be improved significantly. In recent advancements in literature, three main cooperative signaling methods have been proposed; amplify and forward [23], decode and forward [21], [22], and coded cooperation [24].

For cooperative communications there are still many key issues that need to be addressed. An important issue is how to choose that who will partner with whom and under what conditions they will partner. Some initial work has been done in [25] for partner assignment. Further, in literature only the case of each user having one partner has been analyzed and a related issue is the extension of the proposed methods to multiple partners. Further, in literature it is generally assumed that each user transmits with equal power and an issue is to device power control schemes for cooperative communication systems [26].

C. *Multicarrier CDMA*

Multicarrier CDMA has emerged as a promising multiple access technique for future generation broadband wireless communication systems supporting various multimedia services. High spectral efficiency and low receiver complexity can be considered as the main advantages of multicarrier CDMA technology. Multicarrier CDMA is a combination of direct sequence-CDMA and OFDM techniques. The main benefit of combining CDMA with OFDM is that the possibility of loosing subcarriers due to severe frequency domain fades is avoided [31]. On the contrary to single-carrier (SC)-DS-CDMA systems, in multicarrier CDMA systems, high complex receivers are not necessary in the presence of multipath propagation [28]. Multicarrier CDMA is highly suitable for broadband downlink transmission due to synchronism among users [7]. The performance of SC DS-CDMA and multicarrier CDMA schemes with frequency-domain equalization has been investigated in [33].

Multicarrier CDMA transmission schemes are divided into three groups: multicarrier CDMA (MC-CDMA), multicarrier DS-CDMA (MC-DS-CDMA) and multitone (MT)-CDMA. In MC-CDMA, spreading is performed in the frequency domain. In contrast, in MC-DS-CDMA, the symbol sequence is first serial-to-parallel converted into substreams and then each subcarrier stream is spread using the same spreading sequence separately in the time domain. Similar to MC-DS-CDMA, spreading is performed separately on each subcarrier stream in the time domain, but subcarriers are not orthogonal after spreading. Since MT-CDMA systems use long spreading sequences, they can support more number of users than SC-DS-CDMA systems [27]. MC-DS-CDMA is more robust against timing errors and frequency offsets. Due to the synchronism among users, MC-CDMA is more attractive for downlink transmission. Different from MC-CDMA systems, in MC-DS-CDMA systems, it is not required the user synchronism. Hence, MC-DS-CDMA is more suitable for asynchronous uplink transmission [30]. A comparative study of SC DS-CDMA, MC-CDMA and MC-DS-CDMA can be found in [29].

Research on multicarrier-CDMA was hitherto mainly devoted to the areas such as frequency equalization, peak factor reduction, multiuser detection, interference cancelation and theoretical performance/capacity analysis. However, to achieve full potential benefits of multicarrier CDMA technology, recent advances in wireless communication research must be incorporated. In [32], ST block coded transmission scheme is proposed for MC-CDMA systems. Recently, a MIMO MC-CDMA scheme is developed with Turbo receiver processing in [7]. Nevertheless, further investigation might be required in the areas such as channel-coded multicarrier CDMA, reduced complexity detection schemes and MIMO multicarrier CDMA. Furthermore, developing efficient channel estimation (and tracking) schemes, specially applicable for fast fading channel environments, would be another important research challenge. More realistic analysis for packet type data and also with packet scheduling is also needed. Development of adaptive modulation schemes that exploit the channel variation in both the frequency and time domain would be another interesting research topic.

D. Cognitive Radio/Software defined Radio

The new insights into the use of the spectrum have challenged the traditional approaches to the spectrum management. Actual measurements have shown that most of the allocated spectrum is largely underutilized [34]. Similar views about the underutilization of the allocated spectrum have been reported by Spectrum-Policy Task Force appointed by Federal Communications Commission (FCC) [35]. Spectrum efficiency can be increased significantly by making it possible for secondary users (users to whom frequency band has not been allocated) to get access to the frequency bands allocated to the primary users. Cognitive radio [36], [37] has been proposed as the means to improve spectrum efficiency by exploiting the unused spectrum in dynamically changing environments. Cognitive radio can be described as a disruptive technology that utilize the large amount of unused spectrum in an opportunistic and coordinated basis, without causing harm to the existing services.

Cognitive radio is built on software defined radio [38], which allows cognitive radio to dynamically adjust its transmitter parameters based on interaction with the environment in which it operates. In [39], software radio has been defined as, ”an emerging technology, thought to build flexible radio systems, multiservice, multistandard, multiband, reconfigurable and reprogrammable by software”. The primary goal of software defined radio is to implement the radio as reconfigurable signal processing software running on top of the hardware. The major advantages of software defined radio are features of flexibility of changing from one standard to another and ease of adaptation to various environments.

Cognitive radio has the potential to significantly improve the spectral efficiency but still the fundamental questions of its practicality remain open. Questions like that will there be useful wireless systems (cognitive radios or secondary users) that can work without causing excessive interference to the primary users needs to be answered. Future challenges are to include advancements in physical layer as MIMO, turbo processing and cooperation diversity and advancements in nanotechnology into the design of cognitive radios [40]. Till now the major work in the area of cognitive radios has been done in the physical layer and the work on network and cross layer issues have only started very recently and needs to be addressed in future.

III. Evolution in Wireless Personal Area Networks (WPANs)

Wireless PAN connects devices within reach of an individual, using radio waves. Typical range of a WPAN is 1-10m. WPAN is used to connect computer and its peripherals such as printer, keyboard, mouse, joystick etc, various personal digital assistants (PDAs) and portable computers without using cables. WPAN uses cheap low power devices. Working group 15 of IEEE LAN/MAN standards committee developed various standards for WPAN. Task group 1 of this working group (802.15) deals with Bluetooth technology [41], [42]. Task group 3 and 4 deal respectively with high data rate and low data rate WPANs based on UWB technology [43]. In following subsections we will briefly describe the Bluetooth and UWB technology.

A. Bluetooth

Bluetooth is a standard for short range, low power and low cost wireless communication. Bluetooth devices use unlicensed spectrum in 2.4 GHz band and have a range of 1m to 100m. Bluetooth uses Gaussian frequency shift keying (GFSK) modulation and frequency hopping spread spectrum (FHSS) technique for multiple access. It achieves data rates up to 3 Mbps. The simplest Bluetooth network configuration is a piconet which consists of one master device and seven active slave devices. Master controls the traffic and regulates the channel access of the slaves. Piconets connect together to form a scatternet over which a multihop wireless network can be built [44].

Even though Bluetooth has been widely deployed and provides cheap short distance communication, there are still certain key challenges with Bluetooth which need to be addressed. Bluetooth suffers from interference from other devices operating in 2.4 GHz band [45]. This interference could severely limit the performance of Bluetooth devices as 2.4 GHz band is getting overcrowded very rapidly, partly due to Bluetooth devices themselves. Another major disadvantage of Bluetooth is that the data rates provided are not sufficient for high data rate multimedia applications. Bluetooth faces stiff competition from IEEE 802.15.3 standard which uses UWB technology that not only achieves much higher data rates but is also more robust against narrowband interference. Recently, there are plans to adopt UWB physical layer for Bluetooth to overcome these problems. Another area of concern in Bluetooth is the security. Certain serious security flaws have been discovered in Bluetooth [46]. These problems need to be addressed while maintaining the ease of use. Since Bluetooth supports speech communication, it must also have QoS features.

B. Ultra Wideband

UWB achieves much higher data rates than Bluetooth at very low transmit power levels due to its large unlicensed bandwidth. UWB bandwidth is enough to effectively stream multiple simultaneous high-quality video streams. Its low power consumption improves the battery life of the portable devices. Moreover, UWB technology requires less complex hardware as the transmission takes place in baseband eliminating the need for mixers, RF oscillators or PLLs which are necessary in narrowband systems. Thus, UWB technology is cost effective and UWB devices are more compact. Due to its low spectral density, unlicensed UWB radio emissions do not add up to cause harmful interference to other radio systems operating in dedicated bands. UWB is being used as the physical layer for both high data rate IEEE 802.15.3a wireless personal area network (WPAN) standard and low data rate IEEE 802.15.4a WPAN standard.

Presently, there are two competing UWB technologies for IEEE 802.15.3a standard. One of them is the Direct Sequence (DS)-UWB [47], which is based on DS- Code Division Multiple Access (CDMA) technology and the other is Multi-band Orthogonal Frequency Division Multiplexing (MB OFDM) [48] which is based on OFDM technology. IEEE 802.15.3a standard is designed to meet the demanding requirements of portable consumer imaging and multimedia applications at low power and low cost.

For low data rate IEEE 802.15.4a WPAN standard, a DS-UWB pulsed-type system is being developed. The IEEE 802.15.4a aims at providing low data rate (20-250 kbps) wireless communication with multi-month to multi-year battery life, very low complexity and precise ranging capability. The narrow duration of the direct sequence modulated UWB pulses enables achievement of the stringent ranging accuracy (¡1m) requirements. Potential applications are sensors, interactive toys, smart badges, remote controls, and home automation.

Current research in UWB is mainly focused on designing of transceivers [49] and antennas [50], channel estimation and modeling [51], equalization [52], pulse shaping [53] and characterization of system performance and spectral efficiency of UWB [54]. Coding and modulation techniques for achieving higher multi-user capacity are being studied. Also receiver designs robust to timing jitter and narrowband interference are being explored [55], [56]. MAC layer protocols suited to UWB systems are being designed [57].

IV. Cross-layer Design

Supporting high data rate, real and non real-time multi-class traffic with different quality of service (QoS) requirements is the main target of next-generation wireless networks [58]. Various adaptation techniques (e.g., adaptive modulation, adaptive coding in conjunction with ARQ protocol, adaptive transmission power, etc.) in different layers have been investigated to cope with the time-varying correlated channel and the scarce wireless resources (e.g., power and bandwidth) [59]. Transmitter and receiver diversity techniques with multiple-input multiple-output (MIMO) antenna are also potential enabling technology to attain the goals for the emerging broadband wireless networks [18].

Traditionally, two sets of issues have been analyzed in virtual isolations from each other in the literature [60]. Some authors focus mainly on physical layer channel modeling, modulation and detection, coding, etc., and optimize system performances by adapting only with physical layer parameters. This group of researchers neglects the consideration of practical buffer size and packet arrival statistics. On the other hand, other group concentrates on the higher layer throughput, delay, delay jitter, packet dropping due to overflow and erroneous reception, etc. However, it has been conceived in the recent literature that significant performance gains can be achieved by various cross-layer approaches. The cross-layer adaptation techniques jointly consider optimizing physical layer parameters (e.g., spectral efficiency, transmission power, BER, etc.) and higher layer parameters (e.g., delay, packet dropping, PER, throughput, fairness, etc.) in an integrated framework [61].

The challenges of the next-generation wireless network design are to consider all of the enabling technologies in an integrated framework to optimize system performance across all the layers [62]. Smart cross-layer adaptation techniques for MIMO systems have to be designed that take into consideration both the physical layer and higher layer issues. Both the multi-user diversity and fairness issues have to be considered in an integrated way [58], [62]. It is also important to consider buffer dynamics since for practical system its size is finite, and proper input packet arrival statistics in addition to channel fading statistics [61]. Multi-carrier transmissions have to be included and investigated in the general framework [58].

V. Quality of Service (QoS) Provisioning

Next generation wireless communications will have to meet the demands of multimedia applications such as steaming video, IP telephony, teleconferencing, interactive games, distance learning etc. and it would be challenging due to constraints and heterogeneities such as power constraint, bandwidth limitation, different protocols and standards, fading effects and stringent quality of service (QoS) requirements. Provisioning of QoS is a key problem in next generation wireless communication systems. Provisioning of end-to-end QoS would be challenging due to major difficulties of IP based multimedia communication in mobile networks. QoS refers to the set of those quantitative and qualitative characteristics which are necessary in order to achieve the desired functionality/performance of an application or service. From a user's perspective, it is the perceived quality such as picture quality of a video, or the quality of a voice conversation. For cellular data networks, QoS mechanisms have been proposed in the literature in the form of medium access control (MAC) enhancement, scheduling and admission control schemes. However, the emerging broadband networks (e.g. wireless LAN and mesh networks) bring newer challenges and have attracted much attention recently.

There are many future issues in QoS in various layers as network layer, MAC layer and in cross layer design. In network layer, major challenge is to satisfy QoS requirements for dynamic networks and to provide end-to-end QoS. Another important issue for ad hoc networks is QoS based routing as link failure happens because of fading and mobility. In MAC layer challenge is the designing of MAC protocol with QoS mechanisms and to devise scheduling and admission control schemes. The challenge also lies in designing mechanisms which can adapt to emerging applications as network gaming, wireless teleconferencing etc. Further, separate design for network QoS and MAC layer QoS is inefficient and hence, an important issue is jointly optimal design of both layers i.e. cross layer design. It is challenging because of the too many variables that exists in optimization. Recently, issues have aroused to use the cooperative diversity for QoS. For further reading refer to references provided here in [63]–[67].

VI. Wireless Security

Security has always been a major concern in networks where sensitive or confidential information is transferred. In wireless networks such as Wireless Local Area Network (WLAN), security is even more important than wired networks as signal propagation is not confined to a wired. Consequently, an attacker can gain access to the network and sniff data packets without any physical connection to the network (e.x. from a parking slot or a neighboring building). Many wireless technologies such as 3G mobile technologies and WLANs are already supporting the basic security mechanisms such as access security [68], [69]. However, some emerging wireless technologies such as wireless ad hoc and sensor networks have brought new and challenging security problems.

Ad hoc networks have wide range of applications from military operations to civilian applications including disaster recovery and emergency services where the existing infrastructures were damaged. In ad hod networks, mobile nodes act as a router in order to convey information from one node to another node. As the result, malicious nodes can not only eavesdrop and modify data packets but also lunch a denial of service (DoS) attack by for example injecting bogus packets or simply dropping data packets. Identity spoofing, message tampering, blackhole attack [70] and Wormhole attack [71] are a few examples of the attacks that can be employed by malicious nodes. Moreover, providing security in ad hoc networks is a very challenging problem due to the network unique characteristics such as dynamic topology, lack of centralized infrastructure and limited bandwidth, battery lifetime and computational power. Effective security solutions require to consider not only all this characteristics but also all possible attacks in the entire protocol stack. Clearly, ad hoc networks security requirements such as key distribution, secure routing and intrusion detection need to be addressed in order to deploy them in a potentially hostile environment.

Wireless mesh network (WMN) is also a promising wireless technology with many emerging applications such as broadband home networking and community networks [72]. WMNs and ad hoc networks have similar security problems. However, WMN may need different security mechanisms as it has a different architecture than an ad hoc network. Providing security for WMNs is also a challenging problem which need to be addressed in order to convince the customers to subscribe to the service.

A. Nanotechnology for Wireless Communications

Nanotechnology is predicted to generate a multitrillion dollar industry in the next decade or two. Nanotechnology is a technology which consists of the technological developments on the nanometer scale, which is the scale of single atoms and small molecules. As we look into the future of wireless communications, it is necessary that we keep nanotechnology in mind [73]. We are now at a threshold of a revolution the ways in which information is processed. The enhancement in the computing speed due to the recent advancements in nanotechnology, have made the practical implementation of complex receiver schemes such as turbo iterative processing attractive in hand held mobile communication systems. Phenomena's like quantum cryptography, quantum coding and quantum information processing are going to play a major role in the design of future wireless communication systems.

VII. Concluding Remarks

Persistent technological evolution in wireless communications is needed mainly due to emerging demands for broadband packet-based services. In this paper, we briefly discussed the evolution towards the future generation broadband wireless communications systems aiming to provide truly ubiquitous broadband wireless access. We have also presented an overview of recent advances and state-of-the-art research in various aspects of wireless communication. We have mainly focused on the advances in the physical layer, wireless personal area networks (WPANs), cross-layer design, quality of service (QoS) provisioning and wireless security. Future research challenges in each area have also been mentioned.

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