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Super-Broadband Wireless Access Network

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1. Introduction

Today's communication network deployment is driven by the requirement to send, receive, hand off, and deliver voice, video, and data communications from one end-user to another. Current deployment strategies result in end-to-end networks composed of the interconnection of networks each of which can be classified as falling into one of three main categories of network: core, metropolitan and access network. Each component network of the end-to-end communication network performs different roles. Nowadays, the increase in the number and size of access networks is the biggest contributor to the rapid expansion of communication networks that transport information such as voice, video and data from one end-user to another one via wired, wireless, or converged wired and wireless technologies. Such services are commonly marketed collectively as a triple play service, a term which typically refers to the provision of high-speed Internet access, cable television, and telephone services over a single broadband connection. The metropolitan networks perform a key role in tripleplay service provision in delivering the service traffic to a multiplicity of access networks that provide service coverage across a clearly defined geographical area such as a city over fiber or wireless technologies infrastructure. The core networks or long haul networks are those parts of the end-to-end communication network that interconnect the metropolitan area networks. The core network infrastructure includes optical routers, switches, multiplexers and demultiplexers, used to deliver triple play service traffic to the metropolitan networks and route traffic from one metropolitan network to another.

Fig. 1, shows a simplified diagram of network connecting tripleplay service providers to end-users of the service. In this network, the uplink traffic from the end-users is input to the network via wireless or wired access network connections in the user's home. The packets associated with this traffic are multiplexed together and forwarded to the local metropolitan network for delivery to a long haul network for transporting to the service providers' access network and hence to the service provider. The downlink traffic from different service providers which is typically traffic corresponding to requested services is input to the network via local access network connections in the service provider premises. The downlink traffic from a particular access network is multiplexed together and delivered to the local metropolitan network for forwarding to a core network (or in some cases another metropolitan network) and hence to the end-users access networks for delivery to the end users. As many access networks are connected to a metropolitan network the traffic data rates throughout a metropolitan network are significantly higher than those throughout an access network. As many metropolitan networks feed traffic into a core network the traffic handling capabilities of a core network are significantly higher than those of a metropolitan network. The network traffic on core networks is expected to reach the order of hundreds exabytes in the near future, (Laskar et al., 2007). The rapidly changing face of networked communications has seen a continued growth in the need to transfer enormous amounts of information across large distances. A consequence of this is that technologies that are used extensively for transferring information such as coaxial cable, satellite, and microwave radio are rapidly running out of spare capacity, (Mcdonough, 2007).

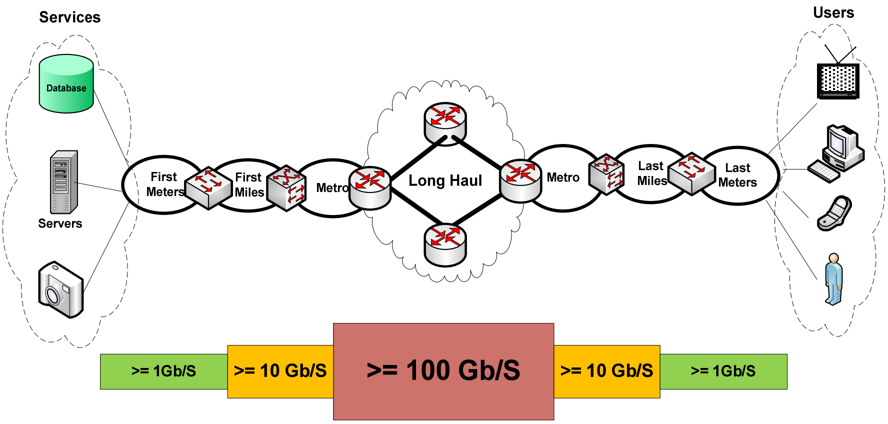


Fig. 1. Near term future network capacity requirements.

Therefore, transportation of the traffic volumes that will be demanded by users in the near future will require significantly greater network transmission bandwidth than that provided by the current infrastructure. Consequently, in the near term each category of component network of existing end-to-end networks will face different and increasingly difficult challenges with respect to transmission speed, cost, interference, reliability, and delivery of the demanded traffic to or from end-users. Currently, super-broadband penetration and the on-going growth in the internet traffic to and from business and home users are placing a huge bandwidth demand on the existing infrastructure.

Broadband wireless sits at the confluence of two of the most remarkable growth stories of the telecommunication industry in recent years. Wireless and broadband have each enjoyed rapid mass-market adoption. Wireless mobile services grew from 11 million subscribers worldwide in 1990 to more than 5 billion by the end of 2010. The world's largest manufacturer of mobile phones has forecast that the number of mobile users accessing the internet via mobile broadband will grow to over 2 billion globally by the end 2014. Fixed broadband subscribers numbered only 57,000 in 1998 and rapidly increased to 555 million subscribers by the end of 2009. The number of fixed broadband subscribers is projected to exceed 720 million by 2015 despite the current economic situation, (OASE, 2010; ITU, 2011). The growth in the numbers of mobile telephone subscribers, broadband and internet users over the last decade and the projections for the growth in these numbers are depicted in Fig. 2.

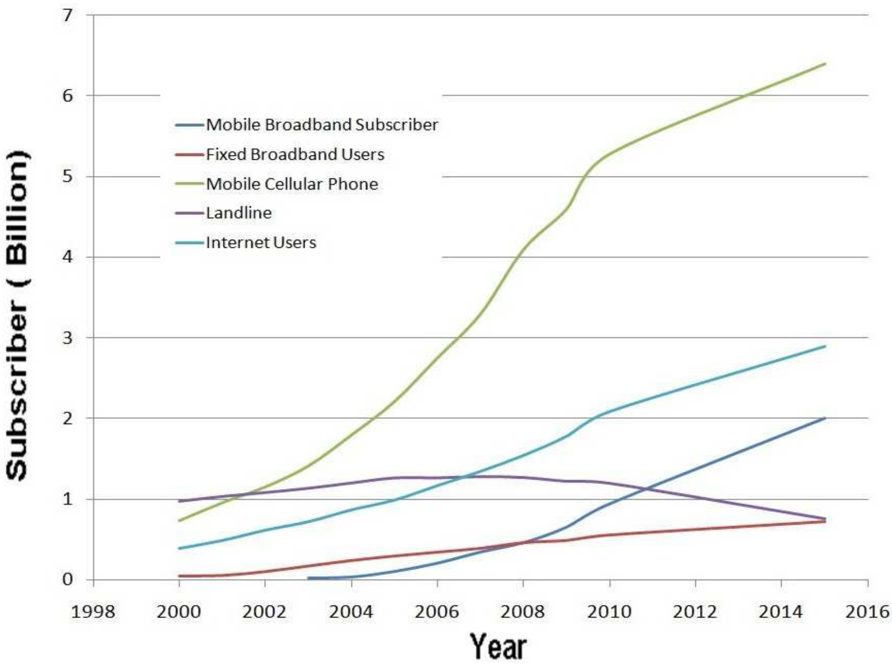


Fig. 2. Worldwide subscriber growth in the numbers of mobile telephony, internet, and broadband access users.

It follows that the demand for use of the available radio spectrum is very high, with terrestrial mobile phone and broadband internet systems being just one of many types of access technology vying for bandwidth. Mobile telephony and internet applications require the systems that support them to operate reliably in non-line-of-sight environments with a propagation distance of 0.5-30 km, and at velocities up to 100 km/h or higher. These operating environment constraints limit the maximum radio frequency the systems can use as operating at very high frequencies, i.e. approaching microwave frequencies, results in excessive channel path loss, and excessive Doppler spread at high velocity. This limits the spectrum suitable for mobile applications making the value of the radio spectrum extremely high. As an example, in Europe auctions of 3G licenses for the use of radio spectrum began in 1999. In the United Kingdom, 90 MHz of bandwidth was auctioned off for £22.5 billion (GBP). In Germany, the result was similar, with 100 MHz of bandwidth raising $46 billion (US). This represents a value of around $ 450 million (US) per MHz. The duration of these license agreements is 20 years. Therefore, it is vitally important that the spectral efficiency of the communication system should be maximized, as this one of the main limitations to providing low cost high data rate services, (OMEGA ICT Project, 2011; Yuen et al., 2004). By deploying converged fiber and wireless communication (Fi-Wi) technologies, network operators and service providers can meet the challenges of providing low cost high data rate services to wireless users. Only the relatively huge bandwidth of a fiber-optic access network can currently support low cost high data rate services for wired and wireless users.

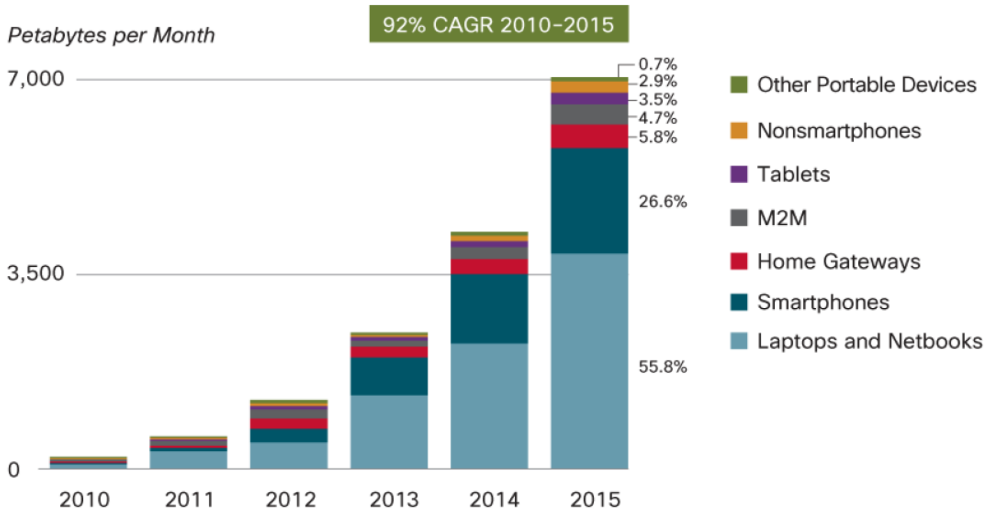
This chapter makes the case for radio over fiber (RoF) networks as a future proof solution for supporting super-broadband services in a reliable, cost-effective, and environmentally friendly way.

This chapter is organized as follows: In Section II, the evolution of Internet traffic driven by the growth in wired and wireless subscribers worldwide is discussed. In Section III, solutions for cost effective transportation of traffic volumes in line with the demand expected as a result of anticipated growth in interactive video, voice communication and data services are presented. In Section IV, the radio over fiber (RoF) network as a future proof solution for supporting super-broadband services is described as a reliable, cost-effective and environmentally friendly technology. Finally, concluding remarks are given in Section V.

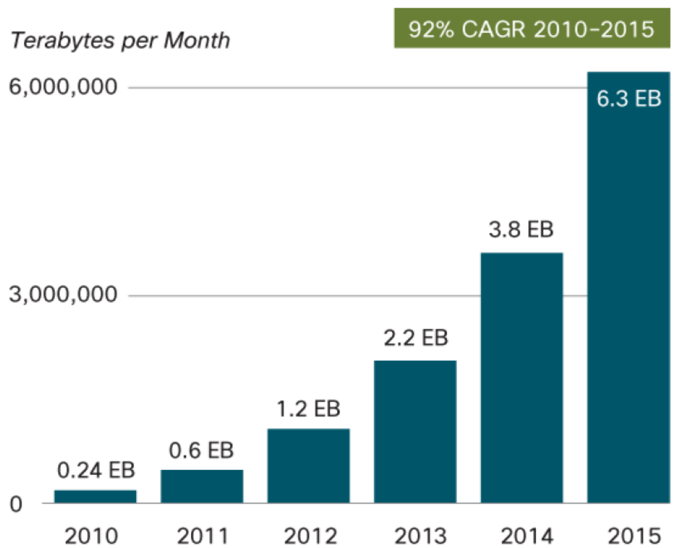
2. Evolution of data traffic and future demand

Globally, mobile communication data traffic is expected to increase 26-fold between 2010 and 2015 and reach 6.3 exabytes per month by 2015. Furthermore, the compound annual growth rate (CAGR) of mobile data traffic is expected to reach 92 percent over the period 2010 to 2015. Moreover, during 7 years from 2005 to 2012 mobile data traffic will have increased a thousand-fold. In 2010, about 49.8% of mobile data traffic was video traffic. By deploying a converged fiber and wireless communication (Fi-Wi) technologies, the operators and service providers can meet the challenges they face from the continued dramatic growth in mobile data traffic volumes.

By the end of 2011, video traffic over mobile networks reached about 52.8% of the total traffic on mobile networks. It is expected that almost 67% of the world’s total mobile traffic will be video by 2015 and that the volume of video traffic on mobile networks will have doubled every year over the period 2010 to 2015, (FP7, 2010, Cisco Visual Networking Index, 2011). In Fig. 3, the worldwide growth in data traffic rates per month are compared for mobile terminals and other devices. Fig. 3 (a) shows the anticipated growth of data traffic by user terminal type for the following terminal types: tablets, machine-to-machine (M2M), home gateways, smartphones, laptops, non-smartphones, and other portable devices. It is predicted that in 2015 82.4% of all network data traffic, about 5.768 exabbytes per month, will be being transported to and from just by two types of portable wireless devices. Specifically, it is predicted that 55.8% and 26.6% of all network data traffic will relate to laptop and smartphone users, respectively. As shown in Fig. 3 (b), the expectation is that the data traffic rate relating to mobile devices will be about 6.3 exabaytes per month by the end of 2015, (Cisco Visual Networking Index, 2011).



(a)



(b)

Fig. 3. The anticipated growth of data traffic (a): by user terminal type , (b) forecast of mobile data traffic growth by 2015, (Cisco Visual Networking Index, 2011).

High-Definition Television (HDTV) can now be provided in many countries throughout the world while Ultra High Definition Television (UHDTV) is now being studied in Japan as the most promising candidate for next-generation television beyond HDTV, and Super-High-

Definition Television (SHDTV). UHDTV consists of extremely high-resolution imagery and multi-channel 3D video and sound to give viewers a stronger sensation of presence. The UHDTV project's commercializing outlook is to become available in domestic homes over the period 2016 to 2020. For example, in 2005, NHK demonstrated a live relay of a UHDTV program using dense wavelength division multiplexing (DWDM) with 24 Gbit/s speed over a distance of 260 km on a fiber optic network. In 2006 NHK demonstrated a solution for bandwidth efficient delivery of UHDTV, utilizing a codec developed by NHK the video was compressed from 24 Gbit/s to 180–600 Mbit/s and the audio was compressed from 28 Mbit/s to 7–28 Mbit/s, (Sugawara et al., 2007; Kudo, 2005).

3. Deployment of super-broadband services

Globally the evolution of internet video services will be in the three following phases: 1) experiencing a growth of internet video as viewed on the PC, 2) internet delivery of video to the TV, and 3) interactive video communications, Fig. 4. Considering the future ultra high, super high and high definition resolution of end-user demanded and generated data traffic, each phase will impact on a different aspect of the end-to-end delivery network such as bandwidth, spectral efficiency, cost, power consumption, architecture, and technology. In addition to internet video, there is very high growth in the internet protocol (IP) transport of cable and mobile IPTV, and video on-demand services, (OASE, 2010).

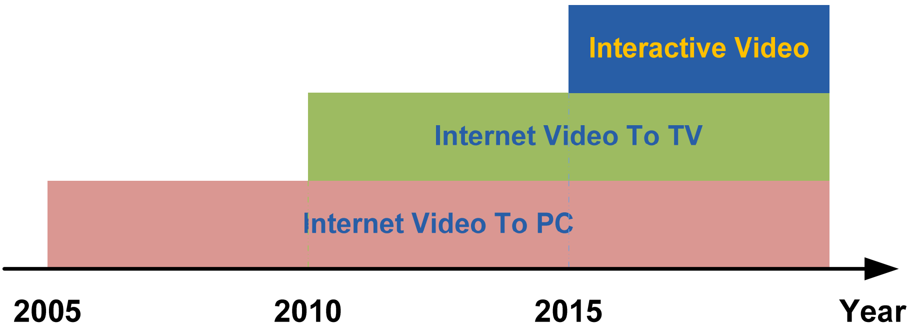


Fig. 4. Three waves of consumer Internet traffic growth.

Mobile voice services are already considered a necessity by many end-users, and mobile data, video, and TV are now becoming an essential part of some end-users' lives. The number of mobile subscribers' is growing rapidly and is expected to reach over 6.2 billion subscribers by 2015. Mobile users' bandwidth demand due to video services is increasing. Therefore, there is an essential need to increase the capacity of delivery networks for mobile broadband, data access, and video services to retain subscribers as well as keep cost in check.

Major considerations in planning the deployment of next-generation mobile networks are an increasing need for service portability and interoperability driven by the proliferation of mobile and portable digital devices and an accompanying need for the networks to enable such devices, including smartphones, tablets, laptops, and non-smartphones, to connect to them seamlessly. The expansion of wireless ubiquity will result in increasing numbers of consumers depending on mobile networks creating a need for increasing economies of scale to deliver lower cost per-bit. According to a prediction of future combined consumer and advertiser spend on mobile media and associated data, which includes handset browsing, mobile applications, mobile games, mobile music, mobile TV, ringtones, wall papers and alerts, spend will rise from just under $75 billion at the end of 2010 to $138 billion by 2015, at a 13.17 CAGR, (MacQueen, 2010). Moreover, it is predicted (RNCOS Industry Research Solution, 2011) that the number of mobile TV subscribers worldwide will grow at a CAGR of around 43% during 2011-2014 to reach about 792.5 million by the end 2014.

In response to this remarkable development, core and metro networks have experienced a tremendous growth in bandwidth and capacity with the widespread deployment of fibre-optic technology over the past decade, (OASE, 2010). Fiber optic transmission has become one of the most exciting and rapidly changing fields in telecommunication engineering. Fiber optic communication systems have many advantages over more conventional transmission systems. They are less affected by noise, are completely unaffected by electromagnetic interference (EMI) and radio frequency interference (RFI), do not conduct electricity and therefore, provide electrical isolation, are completely unaffected by lightning and high voltage switching, and carry extremely high data transmission rates over very long distances, (Guo et al., 2007). As shown in Fig. 1, data speeds in metro and long-haul systems are evolving from 10 Gbps to 40 Gbps transmission. A 100 Gbps per wavelength channel system is taking shape as a next step for core and metro networks, (FP7, 2010). Wavelength division multiplexing (WDM) techniques, such as: dense WDM (DWDM), and highly DWDM (HDWDM) offer the potential for huge bandwidth fiber optic networks with all-optical switching and routing in the future.

In the recent years wireless services have been taking a steadily increasing share of the telecommunications market. End users not only benefit from their main virtue, mobility, but are also demanding ever larger bandwidth. Larger wireless capacity per user requires the reduction of the wireless cell size, i.e. establishing pico-cells. These can be realised using Wi-Fi systems based on the wireless Local Area Network (LAN) IEEE 802.11n standard which offers data rates of up to 600 Mbit/s. Furthermore, the Wi-Fi Alliance and the Wireless Gigabit Alliance (WiGig) announced that they will cooperate on multi-gigabit wireless schemes that are likely to bring robust wireless networking from the 60 GHz frequency band to consumers whose devices are equipped with Wi-Fi. The partnership will pave the way for new wireless devices that will operate in the 2.4, 5 and 60 GHz bands. It is anticipated that data transfer rates up to 7 Gbps can be achieved, although the highest data rates are is likely to be available only over short distances within living room-sized areas. Nevertheless, the highest rates will be more than 10 times faster than 802.11n (Anthony, 2011). Furthermore, Worldwide interoperability for Microwave Access second generation (WiMAX 2), the marketing name for systems based on the IEEE 802.16m standard, is expected to expand capacity to 300 Mbps peak rates via advances in antennas, channel stacking and frequency re-use over the period 2012 to 2013, (Schwarz, 2011). Looking further ahead the recently ratified IEEE 802.15.3c standard has been defined for the frequency band of 57.0–66.0 GHz, allocated by regulatory agencies in Europe, Japan, Canada, and the United

States. According to this standard, single carrier mode in millimeter wave PHY supports a variety of modulation and coding schemes (MCSs) that support up to 5 Gb/s, (Guo and Kuo, 2007).

Super-broadband access not only provides faster web surfing and quicker file download, but also enables several multimedia applications such as real-time high definition audio and video streaming, multimedia conferencing, and interactive gaming. Broadband connections are currently being used for voice telephony using Voice-over-Internet-Protocol (VoIP) technology. More advanced broadband access systems, such as fiber to the home (FTTH) and very high data rate digital subscriber line (VDSL), enable applications such as entertainment–quality video, including HDTV, and Video on Demand (VoD) to be provided, but for SHDTV and UHDTV services a super-broadband network is essential. As the broadband market continues to grow, several new applications are likely to emerge and it is difficult to predict which ones will succeed in the future.

Broadband wireless is about bringing the broadband experience to a wireless context, which offers users certain unique benefits and convenience. There are two fundamentally different types of broadband wireless services. The first attempts to provide a set of services similar to that of the traditional fixed-line broadband but using wireless as the medium of transmission. This type, called fixed wireless broadband, can be thought of as a competitive alternative to DSL or cable modem. The second type of broadband wireless, called mobile broadband, offers the additional functionality of connectivity in mobility. Mobile broadband attempts to bring broadband applications to new user experience scenarios and hence can offer the end-user a very different value proposition.

Long Term Evolution (LTE) is a new radio platform technology that will allow operators to achieve even higher peak throughputs than High Speed Packet Access evolution (HSPA+) in higher spectrum bandwidth. Furthermore, the overall objective for LTE is to provide an extremely high performance radio-access technology that offers full vehicular mobility and can readily coexist with HSPA and earlier networks. Because of scalable bandwidth, operators will be able to migrate their networks and users from HSPA to LTE easily over time. LTE assumes a full IP network architecture, (Rysavy Research, 2007).

Fig. 5 shows the evolution of the 3GPP family of standards towards LTE Advanced (Chang et al., 2007; Rodrigo et al., 2009). LTE uses OFDMA (Orthogonal Frequency Division Multiplexing Access) on the downlink and FDMA (Frequency Division Multiple Access) on the uplink for better power performance of the end-user’s handset, which is well suited to achieving high peak data rates in high spectrum bandwidth, achieving peak rates in the 1 Gbps range with wider radio channels. However, wider channels would result in highly complex terminals and is not simply achievable with the conventional communication infrastructure. Moreover, access bandwidth requirements for delivering multi-channel HDTV, SHDTV, and UHDTV signals and online gaming services are expected to grow beyond several Gbps in the near future and the current subscriber access networks have not been scaled up commensurately. To avoid being the bottleneck in the last miles and last meters, and exploit the benefits of both wired and wireless technologies, mobile and wireless communication service providers and operators are actively seeking convergent network architecture to deliver multiple super-broadband services to serve both fixed and mobile users, (Nokia, 2009; PIANO+, 2010).

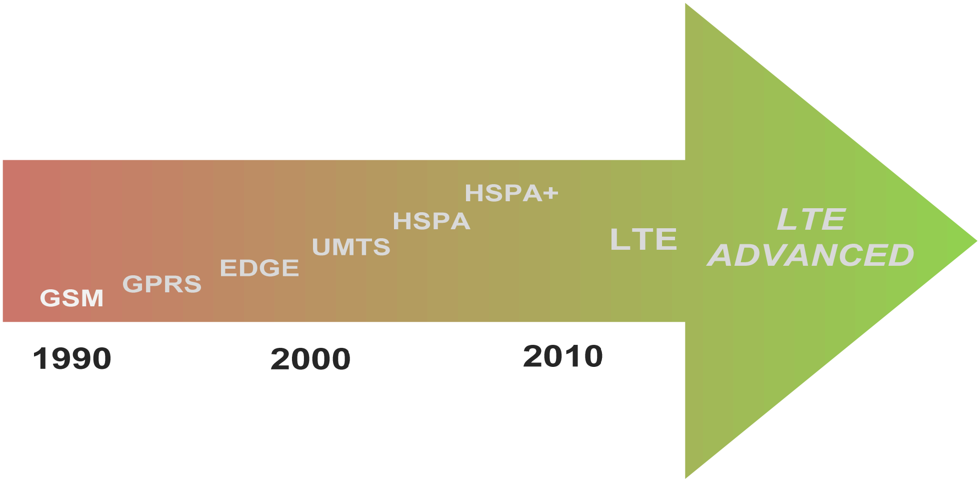


Fig. 5. Evolution of the 3GPP family of standards.

In this regard, optical-wireless access technologies have been considered the most promising solution to increase the capacity, coverage, bandwidth, and mobility in environments such as conference centers, airports, hotels, shopping malls, and ultimately to homes and small offices. As a result, research activity in the field of optical networks and converged optical and wireless communication technologies has grown rapidly and steadily over the last several years. This is because optical communication is a promising choice to fulfill the ever-increasing demand on bandwidth via the vast available capacity of optical fiber and its economic cost. Wireless communication technology on the other hand can provide mobility during communication periods and it is entering a new phase where the focus is shifting from voice to high definition multimedia services. Present consumers are no longer interested in the underlying technology; they simply need reliable and cost effective communication systems that can support end-users' demanded services anytime, anywhere, any media, that they want.

3.1 Core and metro networks

The two main categories of network to be considered from the point of view of establishing super-broadband access networks are core and metro networks. In this subsection, the two main challenges facing core and metro networks are discussed. These challenges are realising the bandwidth potential of fiber optic core networks by appropriate wavelength allocation and switching strategies. Therefore in this subsection, the discussion focussed on optical switching paradigms and dynamic wavelength allocation.

The main barrier to the use of most existing core and metro networks for future traffic transportation arises from their active electrical switching and routing systems which delay packets when processing them for switching in the electrical domain. It takes time to convert a signal from the optical to the electrical domain and vice versa. In addition the synchronization and data retiming processing takes time. Indeed, a great part of the research into optical networks is dedicated to transparency in optical networks in order to bypass Optical/Electrical/Optical (O/E/O) conversions in the intermediate nodes of the network. Thus, a number of network protocols such as MPLS (Multi Protocol Label Switching, GMPLS, etc. (Larkin, 2005) together with switching strategies (circuit- burst- or packet-switching) are proposed for data transparency in the network. Among the switching strategies, burst switching is the most compatible with the current optoelectronic technologies in terms of data transparency and switching speed. Packet switching is more efficient for data communication, but due to the limited speed of electrical networks compared to the current optical networks and the insufficient evolution of all-optical signal processing alternatives, packet based optical networks are not a practical solution for transparent optical networks. A comparison of the all optical switching schemes, optical circuit switching (OCS), optical burst switching (OBS) and optical packet switching (OPS) is shown in Fig. 6.

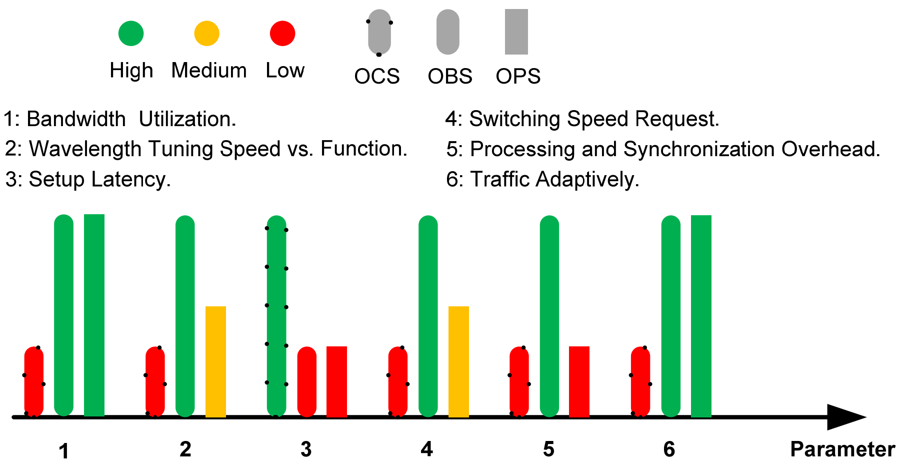


Fig. 6. Comparison of all-optical switching technologies in terms of relative magnitudes of performance measures.

Optical packet switching (OPS) is a viable candidate switching scheme for future networks because it is a purely-connectionless networking solution that is fully compatible with IP-centric data traffic and offers the finest network granularity, the best bandwidth utilization, flexibility, high-speed, and the ability to use the resources available economically.

OPS places more demanding prerequisites on the network than OBS because it processes packets on the fly. The most feasible approach to implementing of OPS involves processing synchronously transmitted packets with fixed lengths. However, in this case the hardware overhead is on the implementation of the packet synchronizer at the input to the switch. Despite their feasibility limitations, OPS demonstrators assisted the development of numerous ultra-fast switching and processing techniques regarding wavelength conversion, header encoding/decoding and processing, label swapping, fast clock extraction, and regeneration.

The main challenges in OPS are the implementation of the optical header processing mechanism, the development of an intelligent switch controller, the realization of ultra fast switching at a nanosecond timescale, and the exploitation on buffering mechanisms to reduce packet blocking (Rodrigo et al, 2009; Raffaelli et al. 2008; Le Rouzic et al., 2005).

Furthermore, the channel allocation and spectral efficiency are other key points for super-broadband network deployment. There are different schemes for channel allocation and multiplexing techniques such as wavelength division multiplexing (WDM), Dense-WDM(DWDM), Highly DWDM, Orthogonal WDM (Goldfarb et al., 2007; Llorente et al., 2005) that are suitable for super-broadband network deployment. The WDM multiplexing based schemes are in addition to multiplexing schemes including time, frequency, and code division multiplexing techniques, which are used in current wired and wireless communication networks and perform well on them. Moreover, cognitive channel and spectrum allocation improves the network's throughput and reduces the cost-over head significantly.

3.2 Access network

Ultra-fast and super-broadband are recognized as becoming increasingly important as demands for bandwidth multiply. Investment in the development of next-generation optical-wireless converged access technologies will enable a future network to be deployed that will radically reduce Fiber-Wireless (FiWi) infrastructure costs by removing local exchanges and potentially much of the metro network. To integrate fiber and wireless technologies, there are important challenges. First, it will be crucial to have mechanism in place to control system load, which will translate into the physical characteristics of the different radio access technologies of wireless systems, the variability of users' requirements and the data rate of on-going wireless connections, complicating the resource management/sharing in FiWi access networks. This raises technical issues such the required protocol interfaces between the resource management entities of tightly coupled networks, and calls for the design of very flexible and effective protocols to allow enhanced routing and link adaptation that makes the best usage of the available resources while dynamically accommodating the users' traffic properties and quality of services requirements.

3.2.1 Passive optical network

There are different topologies for deploying the fiber network from a central exchange station to end-user's premises such as: 1) point-to-point (P-to-P): where individual fibers run from the central station to end-users, 2) point-to-multi-point (P-to-MP) active star architecture: where a single feeder fiber carries all traffic to an remote active node close to the end-users, and from there individual short branching fibers run to the end-users. In this architecture, the fiber network implementation cost is less than that of a point-to-point topology but the main disadvantages of this architecture are a) the bandwidth of the feeder fiber is shared between several end-users and the allocated dedicated bandwidth for each end-user is less than in the point-to-point architecture. b) the requirement for active equipment in a remote node will impose some restrictions on network deployment such as the availability of a reliable and uninterruptable power supply, proper space for installation of active equipment, air conditioning and ventilation, and maintenance costs, 3) point-to-multi-point passive star architecture: in which the active node of the active star topology is replaced by a passive optical power splitter/combiner that feeds the individual short range fibers to end-users. This topology has become a very popular and is known as the passive optical network (PON). In this topology, in addition to the reduction in installation cost, the active equipment is completely replaced by passive equipment avoiding the powering and related maintenance costs, (Koonen, 2006).

Besides the technical issues of implementation, the maintenance and operation cost overhead should be accounted for as it plays a key role in choosing a particular architecture. In the P-to-P architecture, for each end-user, two dedicated optical line terminations (OLT) are needed, while, in the P-to-MP scheme, for each end-user one dedicated OLT is required at the end-user side, another shared OLT at the central station is interfaced between several end-users. When the number of customers increases, the system costs of the P-to-P architecture grow faster than those of the P-to-MP architecture, as more fibers and more line terminating modules are needed. Therefore, sharing the implemented infrastructures between several operators, service providers, technologies, and end users is an essential solution to reduce the infrastructure network cost overhead. . As shown in Fig. 7, the initial cost of P-to-P topology ($Cost_{P\text{-}to\text{-}P}(N_1)$) for N_1 users is lower than initial cost of P-to-MP topology ($Cost_{P\text{-}to\text{-}MP}(N_1)$), while by increasing the duct length at point L_0, the $Cost_{P\text{-}to\text{-}P}(N_1)$ crosses the $Cost_{P\text{-}to\text{-}MP}(N_1)$ graph and will be greater than it for fibre lengths greater than L_0. Furthermore, the initial cost of P-to-MP topology for N_2 users, where $N_2 > N_1$, is more cost effective than the initial cost of P-to-P topology for N_2 users.

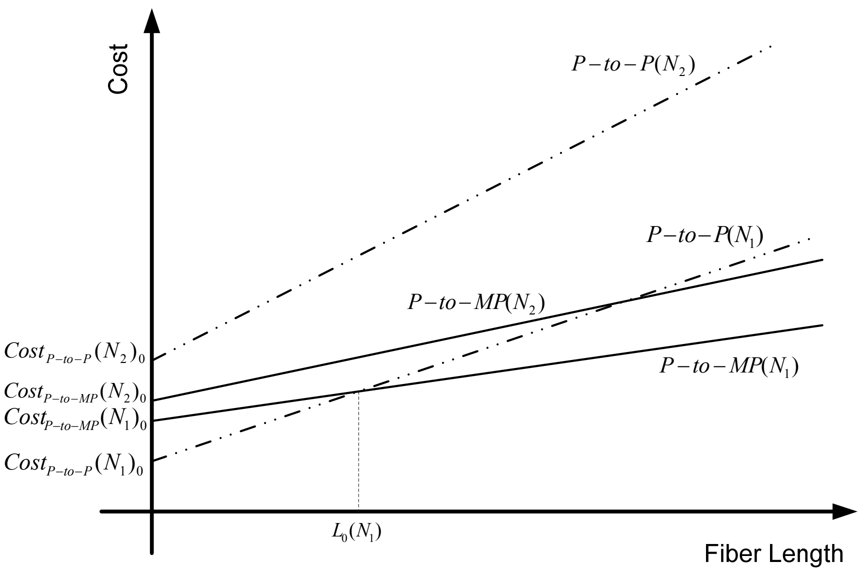


Fig. 7. The comparison of systems cost of FTTH different topology networks versus duct length to end-users premises.

In the P-to-P and P-to-MP active star architectures, each fiber link are only carries a data stream between two electro-optic converters, and the traffic streams of the end-users are multiplexed electrically at these terminals. Therefore, there is no risk of collision of optical data streams. Whereas, the traffic multiplexing is done optically in a Passive Optical Network (PON) topology by integration of the data streams at the passive optical power combiner; to avoid collisions between individual data streams it is necessary to implement a well-designed multiplexing technique. A model of WDM PON network is shown in Fig. 8.

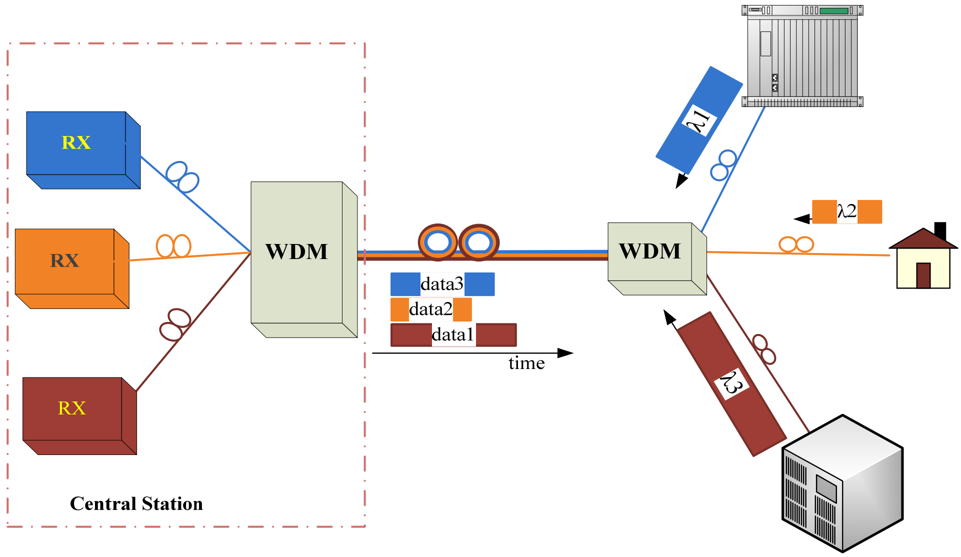


Fig. 8. A model of a point-to-multi-point passive optical network topology.

Several multiplexing techniques are used in PON networks, such as time division multiple access (TDMA), subcarrier multiple access (SCMA), wavelength division multiple access (WDMA), and optical code division multiple access (OCDMA). Excluding, the wavelength division multiplexing technique, these multiplexing techniques are available in wireless or wired telecommunication systems. As shown in Fig. 9, in a WDM PON, each optical network unit (ONU) uses a different wavelength channel to send its packets to an OLT in a central office. The wavelength channels can be routed from the OLT to the appropriate ONUs and vice versa by a wavelength demultiplexing/multiplexing device located at the PON splitting point. This wavelength multiplexing technique constitutes independent communication channels and the network could be able to transport different signal formats; even if the channels use different multiplexing techniques no time synchronization between the channels is needed.

Currently Fiber to the home (FTTH) access technologies provide huge bandwidth to users, but are not flexible enough to allow roaming connections. On the other hand, wireless networks offer mobility to users, but do not possess sufficient bandwidth to meet the ultimate demand for multi-channel video services with high definition quality. Therefore, seamless integration of wired and wireless services for future-proof access networks will lead to a convergence to high bandwidth provision for both fixed and mobile users in a single, low-cost transport platform, This can be accomplished by using the developed hybrid optical and wireless networks, which not only can transmit signals received wirelessly over fiber at the BS, but also simultaneously provide services received over fiber to wireless the end users.

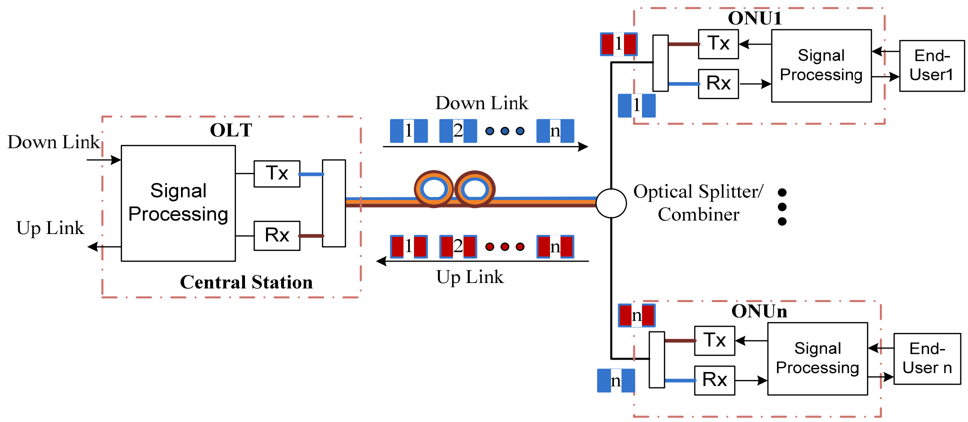


Fig. 9. WDM over a passive optical network.

3.2.2 Dynamic wavelength allocation

By creating multiple wavelengths in a common fiber infrastructure, the capabilities of this infrastructure can be extended into an additional dimension. This wavelength dimension can implement independent communication planes between nodes. For example, interconnections in this plane can be asynchronous, have different quality-of-service requirements, and can transport signals with widely differing characteristics. By using the WDM technique, the access network can: 1) separate services; 2) separate service providers; 3) enable traffic routing; 4) provide higher capacity; 5) improve scalability. For assignment of wavelengths to channels the system may follow different scenarios such as: a) static allocation; b) semi-static allocation; c) dynamic allocation, (Urban et al., 2009).

The static wavelength multiplexing scheme sets a virtual P-to-P topology up between two nodes of the network. However, the rapid growth in access network traffic requires flexible and adaptive planning of the wavelength allocation to each different channel or wired and wireless service to avoid congestion resulting from variable data rates demanded or to guaranteed data traffic transportation or services to/from the end-users. By using adaptive wavelength allocation deliverable services will be more cost-effective on the same network and the vast potential bandwidth of fiber optical networks will be more fully exploited. By assigning the wavelength dynamically at the Optical Network Unit (ONU), with flexible wavelength routing, the access network capabilities can be considerably enhanced. This configuration allows setting up a new wavelength channel before breaking down the old one. Alternatively, it may use wavelength tuneable transmitters and receivers, which can in principle, address any wavelength in a certain range. The network management and control system commands to which downstream and to which upstream wavelength channel each ONU transceiver is switched. By issuing these commands from a central station, the network operator actually controls the virtual topology of the network, and thus is able to allocate the networks resources in response to the traffic at the various ONU sites. By changing the wavelength selection at the ONUs, the network operator can adjust the system's capacity allocation in order to meet the local traffic demands at the ONU sites.

In this scenario, as soon as the traffic to be sent upstream by an ONU grows and does not fit anymore within its wavelength channel, the network management system can command the ONU to be allocated another wavelength channel, in which sufficient free capacity is available. Obviously, this dynamic wavelength reallocation process reduces the system's blocking probability, i.e. it allows the system to handle more traffic without blocking and thus it can increase the revenue of the operator from a given pool of communication resources at the central station.

4. Radio over fiber network

The deployment of optical and wireless access network infrastructure is starting to proliferate throughout the world. When these heterogeneous access networks converge to a highly integrated network via a common optical feeder network, network operators can reap the benefits of lowering the operating costs of their access networks and meeting the capital costs of future upgrades more easily. In addition, the converged access network will facilitate greater sharing of common network infrastructure between multiple network operators. Signals received wirelessly and transported over optical fiber (RoF) links will be a possible technology for simplifying the architecture of remote base stations (BSs). By relocating key functions of a conventional BS to a central location, BSs could be simplified into remote antenna units that could be inter-connected with the central office (CO) via a high performance optical fiber feeder network.

Wireless networks typically show considerable dynamics in the traffic loads of their radio access points (RAPs) due to the fluctuations in the number and nature of mobile and wireless services demanded by the networks users. Using the traditional RAPs approach this requires all the wireless nodes to be equipped to cater for the highest capacity likely to be demanded of them which results in the inefficient use of network resources. The design of dynamic reconfigurable micro/pico or femo wireless cells increases network complexity but can significantly increase network efficiency. Similarly, within the optical access network layer WDM PONs allow an extra level of reconfiguration as wavelengths can be assigned either by static or dynamic routing.

The numbers of wireless subscribers are increasing and these subscribers are demanding more capacity for ultra-high data rate transfer at speeds of 1Gbps and up while the radio spectrum is limited. This requirement of more bandwidth allocation places a heavy burden on the current operating radio spectrum and causes spectral congestion at lower microwave frequencies. Millimetre Wave (mm-Wave) communication systems offer a unique way to resolve these problems (Ji, et al. 2009). Radio over fiber (RoF) technology is currently receiving a lot of attention due to its ability to provide simple antenna front ends, increased capacity, and multi wireless access coverage.

An analog RoF (ARoF) also known as RoF is the technique of modulating a radio frequency (RF) sub-carrier onto an optical carrier for distribution over a fiber network. An ARoF link includes optical source, modulator, optical amplifier and filters, optical channel and a photodiode as a receiver, electronic amplifiers and filters; a simple ARoF architecture is shown in Fig. 10. In this system, for a downlink at a central station, a signal received wirelessly is modulated onto an optical carrier generated by a laser diode (LD) and the modulated optical signal is transported over a fiber optic cable. The transported optical signal is detected at base station using a photo diode (PD). The received signal, recovered after performing analog signal processing, is fed to an antenna for wireless transmission. For uplink signal transmission from a base station to the central station, the signal received at an antenna is directed to a low noise amplifier (LNA) and modulated onto an optical carrier that is generated by another LD. The generated optical signal is sent back to the central station for any signal processing and detection. In some cases the RF signal is directly modulated by optical source, but as the laser is usually a significant source of noise and distortion in a radio over fiber link, the laser diode normally exhibits nonlinear behavior. When the LD is driven well above its threshold current, its input/output relationship can be modeled by Volterra series of order 3. Therefore, in high data rate links indirect modulation has better performance. However, an ARoF link suffers from the nonlinearity of both microwave and optical components that constitute the optical link (Al-Raweshidy & Komaki, 2002; Cox, 2004; Li & Yu, 2003). Fig. 11, shows an ARoF link architecture with indirect intensity modulation that uses an electro-optical modulator for modulating an electrical signal representing the information in a wireless signal onto a continuous wave laser source.

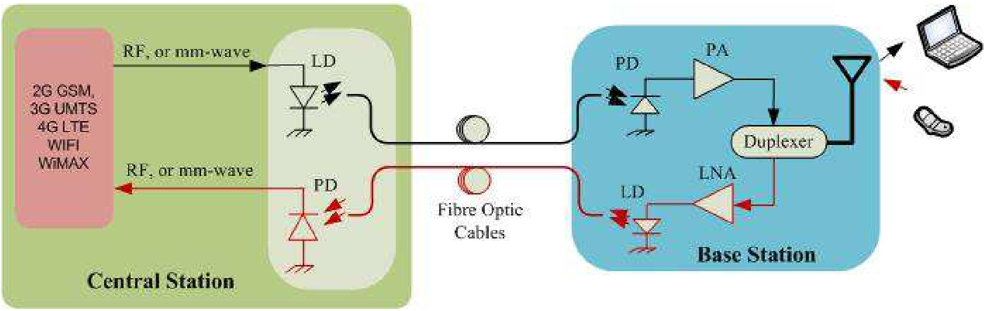


Fig. 10. A direct intensity modulation and detection full-duplex ARoF architecture.

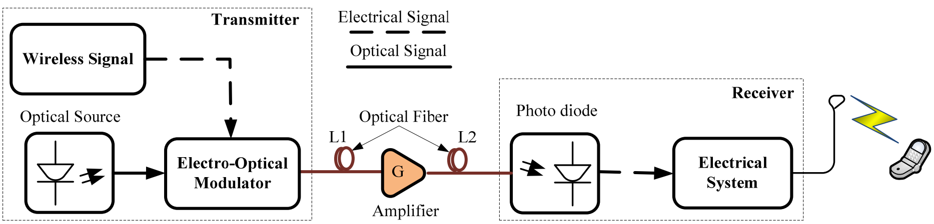


Fig. 11. Downlink architecture of a ARoF link with indirect intensity modulation.

The ARoF technique has been considered a cost-effective and reliable solution for the distribution of future services to wireless devices by using optical fiber with vast transmission bandwidth capacity. An ARoF link is used in remote antenna applications to distribute signals to a Microcell or Picocell base station (BS). The downlink RF signals are distributed from a central station (CS) to a BS known as a Radio Access Point (RAP) through optical fibers. The uplink signals received at RAPs are sent back to the CS for any signal processing. RoF has the following main features: (1) it is transparent to bandwidth or modulation techniques; (2) it only needs simple and small BSs; (3) centralized operation is possible; (4) it supports multiple wired and wireless standards, simultaneously. (5) its power consumption is relatively low. Furthermore, the implementation of the RoF technique faces the following challenges: fiber optic network implementation cost, optical communication components nonlinearity and fiber dispersion. Consequently, in last decade several research projects have sought to develop and discover new solutions to overcome these challenges and broaden the benefits of RoF.

4.1 Radio over fiber's link architecture

The signal that is transmitted over the optical fiber can either be originally an RF, intermediate frequency (IF) or baseband (BB) signal. For the IF and baseband (BB) transmission cases, additional hardware for up converting the signal to the RF band is required at the BS. At the optical transmitter, the RF/IF/BB signal can be modulated onto the optical carrier by using direct or external modulation of the laser light. In an ideal case, the output signal from the optical link will be a copy of the input signal. However, there are some limitations because of non-linearity and frequency response limits in the laser and modulation devices as well as dispersion in the fiber. The transmission of analog signals puts certain requirements on the linearity and dynamic range of the optical link. These demands are different and more exacting than requirements placed on digital transmission systems.

In Fig. 12, typical RoF link configurations are shown, which are classified based on the kinds of frequency bands transmitted over an optical fiber link. In the downlink from the CS to the BS, the information signal from a public switched telephone network (PSTN), an Internet Service Provider (ISP), a mobile telecommunications operator, an Intelligent Transportation System (ITSs) or another CS is fed into the optical network at the CS. The signal that is either RF, IF or BB band modulates an optical signal from a LD. As described earlier, if the RF band is low, it's possible to modulate the LD signal using the RF band signal directly. If the RF band is high, such as the mm-wave band, it's better to use electro- optical modulators (EOMs), like Mach-Zehnder Modulators. The modulated optical signal is transmitted to the BS via optical fibers. At the BS, the RF/IF/BB band signal is recovered by detecting the modulated optical signal by using a PD. The recovered signal, which needs to be upconverted to RF band if an IF or BB signal is to be transmitted to a mobile handset (MHs) via the antenna of the BS.

In the configuration shown in Fig. 12 (a), the modulated signal is generated at the CS in an RF band and directly transmitted to a BS by an EOM, which is called "RF-over-Fiber". At the BS, the modulated signal is recovered by detecting the modulated optical signal with a PD and directly transmitted to a MH. Signal distribution using RF-over-Fiber has the advantage of a simplified BS design but is susceptible to fiber chromatic dispersion that severely limits the transmission distance (Gliese et al., 1996). In the configuration shown in Fig. 12 (b), the modulated signal is generated at the CS in an IF band and transmitted to a BS by an EOM, which is called “IF-over-Fiber”. At each BS, the modulated signal is recovered by detecting the modulated optical signal with a PD, up converted to an RF band, and transmitted to a MH. In this scheme, the effect of fiber chromatic dispersion on the distribution of IF signals is much reduced. However, the antennas of the BSs a RoF system incorporating IF-over-Fiber transport require additional electronic hardware such as an mm-wave frequency LO for frequency up- and down conversion.

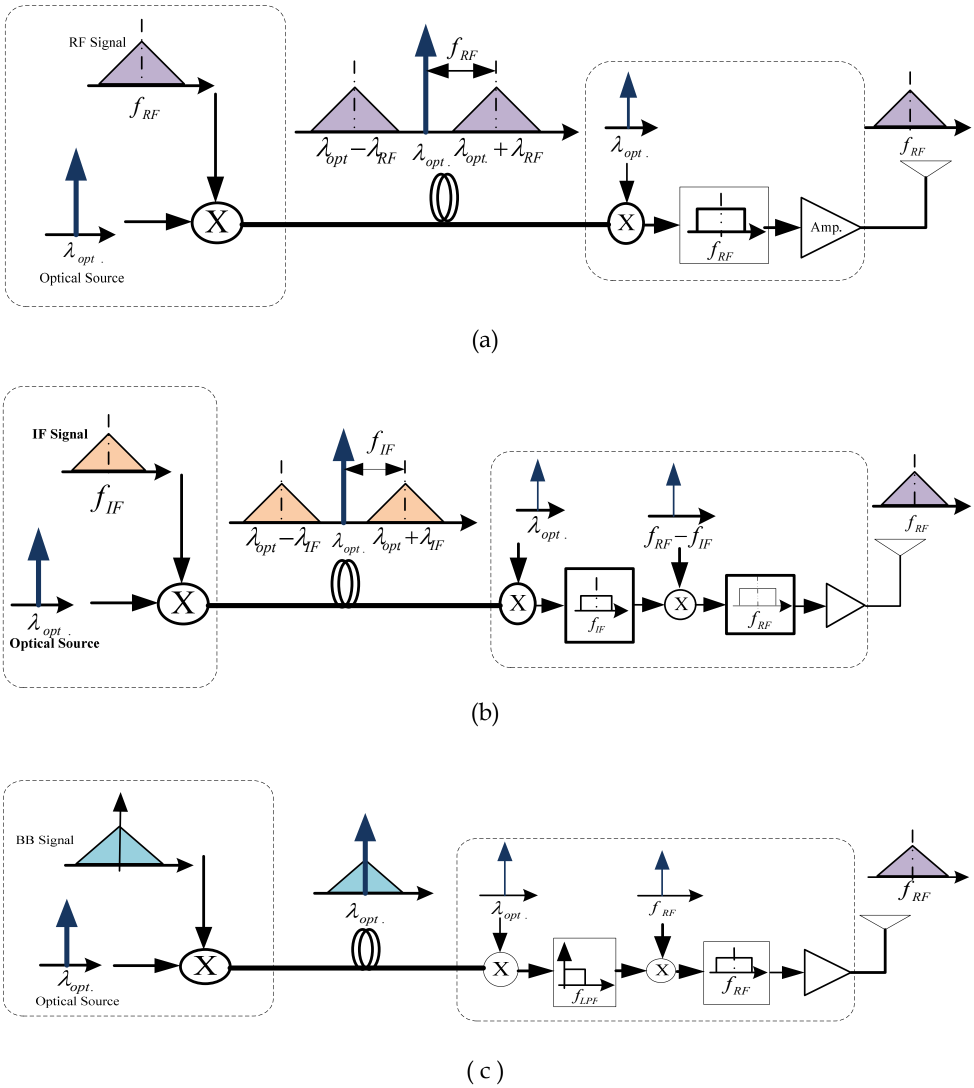


Fig. 12. Different schemes for signal modulation onto an optical carrier for distribution: (a) Radio over Fiber; (b) IF over Fiber; (c) BB over Fiber.

In Fig. 12 (c), the modulated signal is generated at the CS in baseband and transmitted to a BS, which is referred to as “BB-over-Fiber”. At the BS, the modulated signal is recovered by detecting the modulated optical signal with a PD, up converted to an RF band through an IF band or directly, and transmitted to a MH. In baseband transmission, the impact of fiber dispersion effects is negligible, but the BS configuration is the most complex. This is especially important when RoF in mm-wave bands is combined with dense wavelength division multiplexing (DWDM). This increases the amount of equipment at the BSs because an up converter for the downlink and a down converter for the uplink are required. In the RF subcarrier transmission, the BS configuration can be simplified only if an mm-wave optical external modulator and a high-frequency PD are implemented in the electric-to-optic (E/O) convertor and the optic-to-electric (O/E) converter, respectively.

Optical links are mainly transmitting microwave and mm-wave signals by applying an intensity modulation technique onto an optical carrier (Al-Raweshidy & Komaki, 2002). Fundamentally, two methods exist for transmission of the microwave/mm-wave signals over optical links with intensity modulation: (1) direct intensity modulation, (2) external modulation.

In direct intensity modulation an electrical parameter of the light source is modulated by the information RF signal. In practical links, this is the current of the laser diode, serving as the optical transmitter. In Fig. 10, the simplest and most cost-effective architecture of intensity-modulation direct-detection (IMDD) is depicted. In this architecture, the detection is performed using a photo diode (PD). In the direct-modulation process a semiconductor laser directly converts an electrical small-signal modulation (around a bias point set by a dc current) into a corresponding optical small-signal modulation of the intensity of the photons emitted (around the average intensity at the bias point). Thus, a single device serves as the optical source and the RF/optical modulator. An important limitation in this architecture for super broadband access are the restrictions placed on the modulation bandwidth by the laser and the mm-wave band while a simple laser’s linewidth can be modulated to frequencies of several Gigahertzes. Furthermore, it is reported that direct intensity modulation lasers can operate at up to 40 GHz or even higher, but, these are expensive and are not cost-effective in the commercial market. Therefore, at frequencies above 10 GHz, external modulation rather than direct modulation is applied.

In the external modulation technique, Fig. 11, an unmodulated light source is modulated with an information RF signal using an electro-optical intensity modulator. Because the number of BSs is high in RoF networks, simple and cost-effective components must be utilized. Therefore, in the uplink of a RoF network system, it is convenient to use direct intensity modulation with cheap lasers; this may require down conversion of the uplink RF signal received at the BS. In the downlink either lasers or external modulators can be used.

4.2 Application of WDM in a radio over fiber system

The application of WDM in RoF networks has many advantages including simplification of the network topology by allocating different wavelengths to individual BSs, enabling easier network and service upgrades and providing simpler network management. Thus, WDM in combination with optical mm-wave transport has been widely studied (Grifin et al., 1999; Toda et al., 2003).

The implementation of WDM in a RoF network is illustrated in Fig. 13, where for simplicity, only downlink transmission is depicted. Optical mm-wave signals from multiple sources are multiplexed and the generated signal is optically amplified, transported over a single fiber and demultiplexed to address each BS concerned separately. A challenging issue is that the optical spectral width of a single optical mm-wave source may approach or exceed WDM channel spacing. Therefore, there have been several reports on dense WDM (DWDM) applied to RoF networks (Grifin et al., 1999; Grifin, 2000; Toda et al., 2003); by utilizing the large number of available wavelengths in the DWDM technique, the lack of free transmission channels for the deployment of more BSs in mm-wave bands can be overcome. Another issue is related to the number of wavelengths required per BS. It is desirable to use one wavelength to support full-duplex operation. In (Nirmalathas et al., 2001), a wavelength reuse technique has been proposed, which is based on recovering the optical carrier used in downstream signal transmission and reusing the same wavelength for upstream signal transmission.

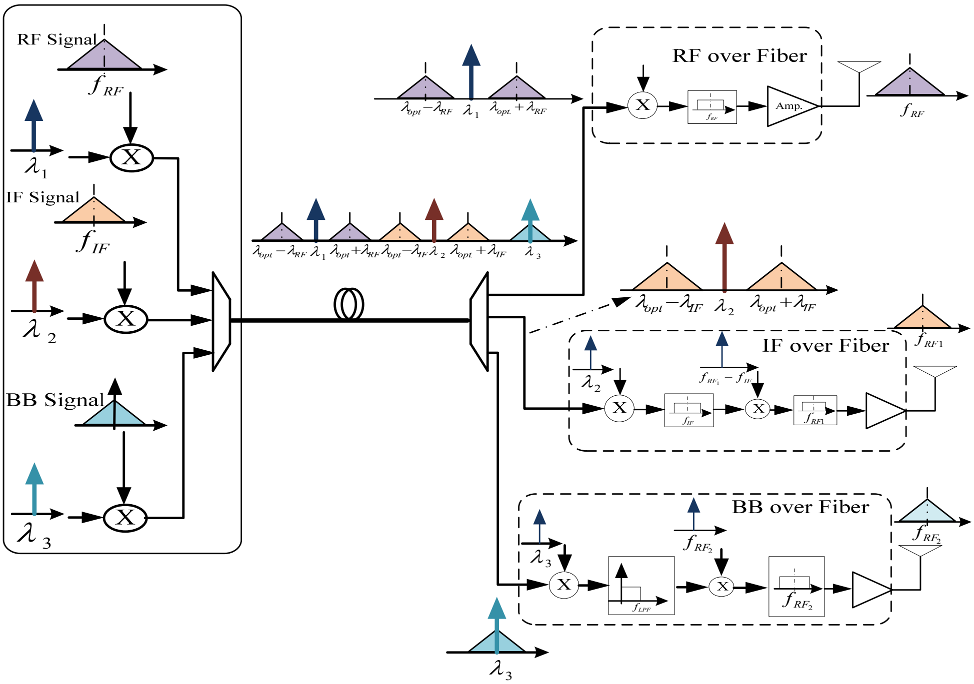


Fig. 13. Schematic illustration of the implementation of WDM in a RoF network.

4.3 Digital radio over fiber

Digital systems are more flexible, more conveniently interface with other systems, are more reliable and robust against additive noise from devices and channels, and achieve a better dynamic range than analog systems. Analog to digital and digital to analog converters (ADC and DAC, respectively) (Walden R. H., 1999) are the link between the analog world and the digital world of signal processing and data handling. In an analog system the bandwidth is limited by devices performance and parasitic components are introduced.

In a Digital RoF (DRoF) system, an electrical RF signal is digitized by using an Electronic ADC (EADC) (Vaughan et al., 1991). Then, the generated digital data is modulated with a continuous coherent optical carrier wave either using a direct modulation technique or by using an external electro-optical modulator as shown in Fig. 14. The modulated optical carrier is transmitted through the fiber. At the base station, after detecting the optical signal using a photo diode, the detected digital data is converted back to the analog domain using an EDAC. Finally, the analog electrical signal is fed to an antenna (Li et al., 2009; Kuwano, 2006, 2008; Lim et al., 2010). Current EDAC systems experience problems such as jitter in the sampling clock (Stephens, 2004; Hancock, 2004), the settling time of the sample and hold circuit, the speed of the comparator, mismatches in the transistor thresholds and passive component values. The limitations imposed by all of these factors become more severe at higher frequencies. Wideband analog to digital conversion is a critical problem encountered in broadband communication and radar systems (Valley, 2007; Kim et al., 2008). For the future beyond Gigabit/s mobile and wireless end-user traffic rates (Abdollahi et al., 2010) due to the limitations of electronic technology for implementing ultra high-speed, high performance EADC, and the resolution of existing EDAC, the deployment of conventional DRoF links (Li et al., 2009; Kuwano, 2006, 2008; Lim et al., 2010) is not simply achievable.

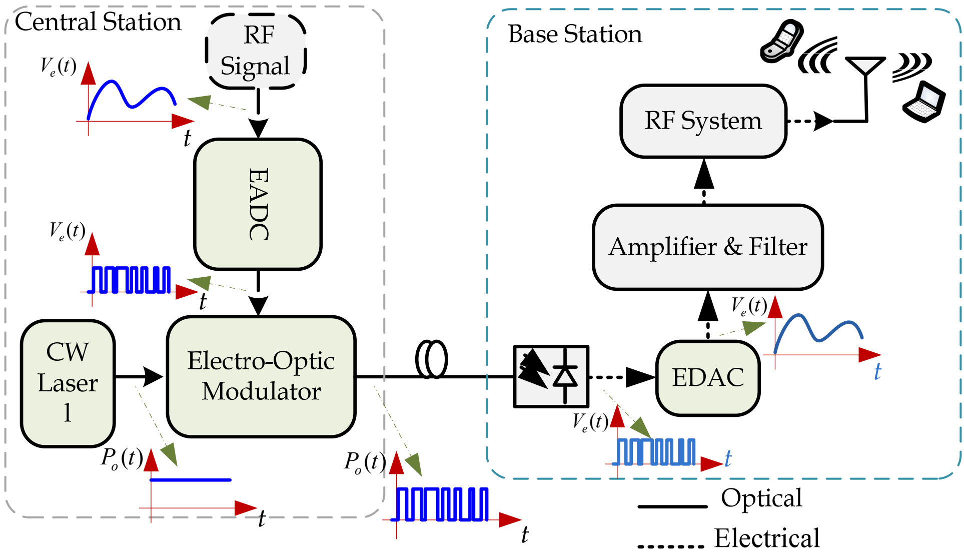


Fig. 14. Conventional DRoF architecture using EADC (downlink) (Li et al., 2009).

Moreover, if a conventional DRoF link could be achieved for Gigabit/s traffic rates the generated digital traffic creates a new challenge, namely, for this architecture to use more electro-optical modulators and photo diodes to implement the wavelength division multiplexing (WDM) technique to diminish the chromatic dispersion caused by the restrictions on the modulation bandwidth for super broadband access by RoF.

4.4 All-photonic digital radio over fiber

An all-photonic DRoF architecture has been proposed (Abdollahi et al. 2011) and is depicted in Fig. 15. This architecture uses an electro-optical modulator, which is simultaneously shared as an optical sampling and modulating device at the CS. A photonic ADC (PADC) by using a mode-locked laser (MLL) and an electro-optical modulator is able to scale the timing jitter of the laser sources to the femtosecond level, (Kim et al. 2007; Bartels et al. 2003), which allows designers to push the resolution bandwidth by many orders of magnitude beyond what electronic sampling systems can currently achieve. The proposed system includes an all-photonic signal processing block for optical quantization and wavelength conversion of the sampled and symmetrically split signal's power. By using the WDM technique to distribute the generated traffic over different wavelengths exceeding the modulation bandwidth of the fiber on a particular wavelength is prevented.

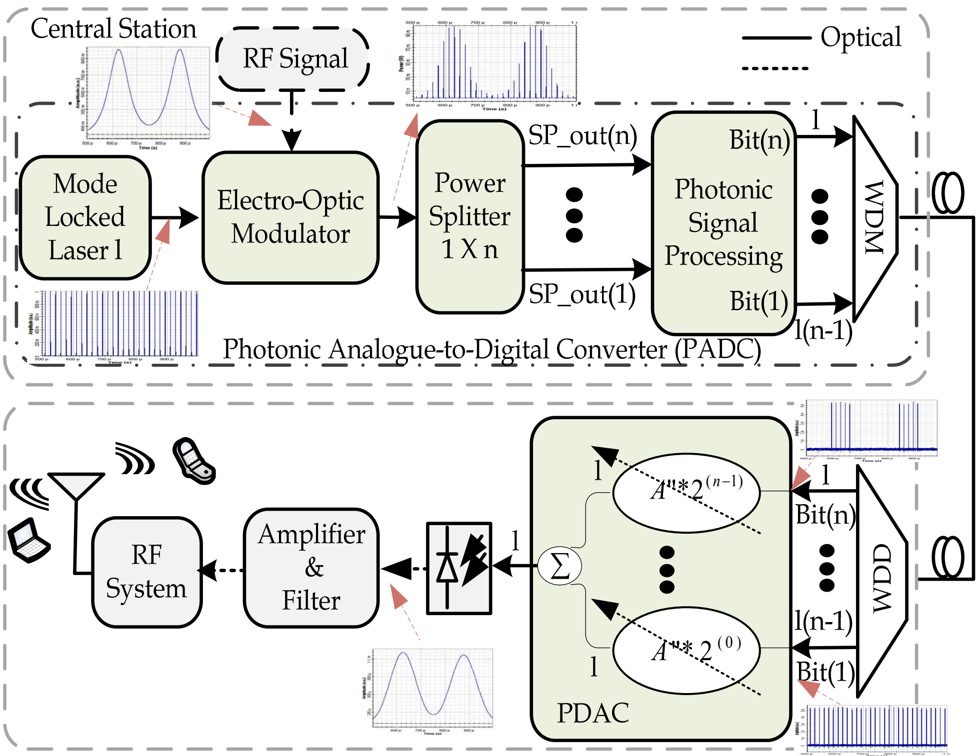


Fig. 15. All-photonic DRoF architecture, (downlink), (Abdollahi et al., 2011).

In Fig. 15, at the CS, the RF signal is sampled and modulated by optical train pulses that are generated using a passive mode-locked laser. The optical power of the sampled pulses is split into n levels using a symmetrical optical splitter, where n denotes the number of quantization bits. Finally, the split signals are fed to a photonic signal processing block for quantization and wavelength conversion operations.

The quantization procedure is performed by the process of Fig. 16 in which A and A' are constant parameters. At the first stage of this process, the stage number is equal to '1' (S=1). In this process entire stages are equal to number of quantization bits, i.e., for each output bit there is a corresponding quantization stage. For quantization of the most significant bit (MSB) the received signal from output number 'n' of the symmetrical splitter SP_out(M) that is defined by the generic number 'M' which is equal to 'n' in this stage. This output optical signal is compared with a reference quantization level equal to '2(M-S) *A'. If the signal power square is greater than or equal to '2(M- S) *A', the output quantization bit is '1'. Otherwise, it is '0'. In this scheme, for performing the pipeline architecture, the quantized bits are converted back into analog domain. Therefore, in stage number '(M-S)', the converted back analog signals from stages 'n' to '(M-S+1)' of the process , are subtracted from the input of the split output signal SP_out(M-S). Then, the given signal is compared with '2(M-S) *A'. The quantization process is repeated in parallel 'n' times for quantizing each sampled optical signal into 'n' bits.

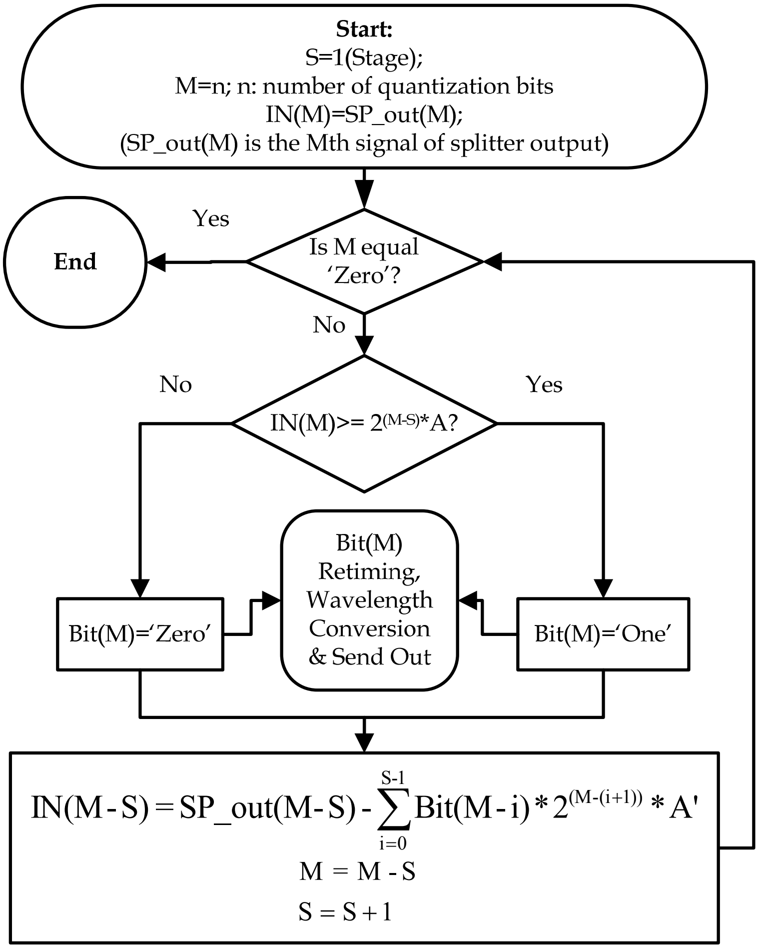


Fig. 16. All-photonic signal processing technique, (Abdollahi et al., 2011).

Subsequent to the wavelength conversion, the digital photonic signals are multiplexed in the wavelength domain by using a WDM and transmitted over a fiber. At the BS, the received signal is demultiplexed by wavelength division demultiplexer (WDD) and fed to the photonic digital-to-analog converter (PDAC). The PDAC subsystem, receives digital optical signals on different wavelengths, and converts them back to the equivalent analog signal at wavelength λ by using a passive PDAC and all-optical wavelength conversion. In the following of this stage, by using a photo diode (PD), the RF signal is recovered and after some RF signal processing it is passed to a multi-band distributed antenna system.

According to results provided (Abdollahi et al., 2011), it is demonstrated that ARoF is more dependent on fiber network impairments and length than DRoF. However, very low phase noise photonic sampling pulses and high speed signal conversion rates can be achieved in an all-photonic DRoF system compared with high-speed electronic circuits generated sampling pulses, signal conversion and processing. Consequently, an all-photonic DRoF system can support a digitized RF signal transmission system for providing super-broadband access to remote distributed wired and wireless access networks. It follows that, compared to the present digital optical communication infrastructures the number of CS would decrease with the introduction of all-photonic DRoF systems and as a result the service providers and network operators cost overheads per bit would be reduced.

5. Conclusions and chapter summery

Mobile and wireless networks generated traffic rates are growing very fast and are expected to double each year. The expectation is for delivering at least 1 Gbps multi-services traffic to each end-user in the near future for personal and multimedia communication services. Therefore, deploying super-broadband networks will be essential for service providers and operators. In this chapter, the convergence of wireless and optical communication technology for deploying future super broadband networks has been discussed.

Fiber optic transmission is rapidly becoming the dominant infrastructure medium for the transportation of fixed and mobile video on the internet. By replacing electronic switching with ultra fast photonic switching fiber optic transmission is expected to meet the need for super-broadband capacity. Radio-over-Fiber is a potential solution for deploying wireless access to broadband and super-broadband seamlessly. It can provide dynamic allocation of resources and can be realised with simple and small BSs with centralized operations. The requirement for more bandwidth allocation places a heavy burden on the current operating radio frequency (RF) spectrum and causes spectral congestion at lower microwave frequencies. Millimeter wave (mm-Wave) communication systems offer a unique way to resolve the bandwidth problems. When heterogeneous access networks converge to a highly integrated network via a common optical feeder network, network operators can reap the benefits of lowering the operating cost of access networks and meeting the capital costs of future upgrades easily. In addition, the converged access network will facilitate greater sharing of common network infrastructure between multiple network operators. Radio signals transportation over optical fiber (RoF) links will be a possible technology for simplifying the architecture of remote base stations (BSs). By relocating key functions of a conventional BS to a central location, BSs could be simplified into remote antenna units that could be inter-connected with a central office (CO) via high performance optical fiber feeder network. Wireless networks typically show considerable dynamics in traffic load of the radio access points (RAPs), due to fluctuations in the number mobile and wireless service users using them and the services they demand.

On the other hand, using the traditional RAPs approach requires equipping all of the wireless nodes for the highest capacity demanded which results in the inefficient use of recourses. The design ofdynamic reconfigurable micro/pico or femo wireless cells increases network complexity but also greatly increases network efficiency. Within the optical access network layer WDM PONs allow an extra level of reconfiguration as wavelengths can be assigned to channels as part of static or dynamic routing. Therefore, integrating dynamic wavelength routing with RoF technology facilitates future flexible, low cost and reconfigurable super-broadband wired and wireless access network.

DRoF links are more independent of fiber network impairments and length than ARoF links. By using very low phase noise photonic sampling pulses and high speed signal conversion rates in place of high-speed electronic circuits generated sampling pulses, signal conversion and processing in an all-photonic DRoF system, digitized RF signal transmission for delivering future super-broadband remote distributed wired and wireless access networks traffic can be realised. Consequently, compared to the present digital optical communication infrastructure the number of CS will decrease in an all-photonic DRoF infrastructure and as a result, service providers and operators cost overhead per bit will be significantly reduced.

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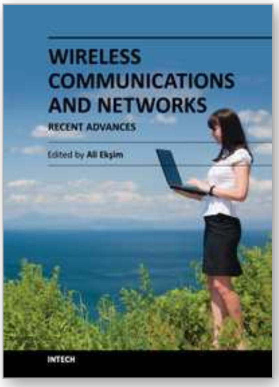

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This book will provide a comprehensive technical guide covering fundamentals, recent advances and open issues in wireless communications and networks to the readers. The objective of the book is to serve as a valuable reference for students, educators, scientists, faculty members, researchers, engineers and research strategists in these rapidly evolving fields and to encourage them to actively explore these broad, exciting and rapidly evolving research areas.

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