Radio over fibre Networks: Advances and Challenges.

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Abstract *This presentation will review the recent developments and advances in Radio-Over-Technologies, highlight the challenges that remain and outline the work being undertaken within the EU Network of Excellence BONE to meet these challenges.*

Introduction

Techniques for the transmission of radio signals over optical fibre have recently been commercialized for the remoting of antennas in cellular wireless systems. Examples of what are known as radio over fibre systems include the 2000 Olympic Games in Sydney[1], Osaka station in Japan and the Bluewater Shopping centre in the UK. Typical applications of these systems are demonstrated in figure 1. Systems currently deployed range from those using primarily designed for in-building applications, such as those available from Zinwave, LGCWireless and ADC or those based on single mode fibre such as BriteCell from Andrew.

One active area of research involving such systems has considered multi-channel operation or investigated extending system reach, for example considering extreme performance limits. Such studies have also considered the interaction of second generation (GSM) and third generation (W-CDMA) wireless system[2], W-CDMA and wireless LAN (WLAN)[3] or WiMAX and UWB co-existence[4].

As these bands become increasingly congested, with growing demands on bit rate, research and development activities have shifted into new areas of the spectrum. Many are considering a shift to frequencies in the millimetre wave bands, such as those around 26 GHz, 29 GHz, 36 GHz and 60 GHz and even into the THz bands[5]. Although these bands offer huge potential bandwidths they also require smaller cells due to lower propagation distances. However, the high oxygen absorption peak at 63GHz may actually have advantages as the radiation distances can be tightly controlled allowing high frequency reuse to be deployed.

Developing systems to operate in these higher frequency bands present new problems; for example the cost associated with the deployment of millimetre wave equipment in the field. These cost increases are also magnified by the need for a high number of base-stations when a pico-cellular

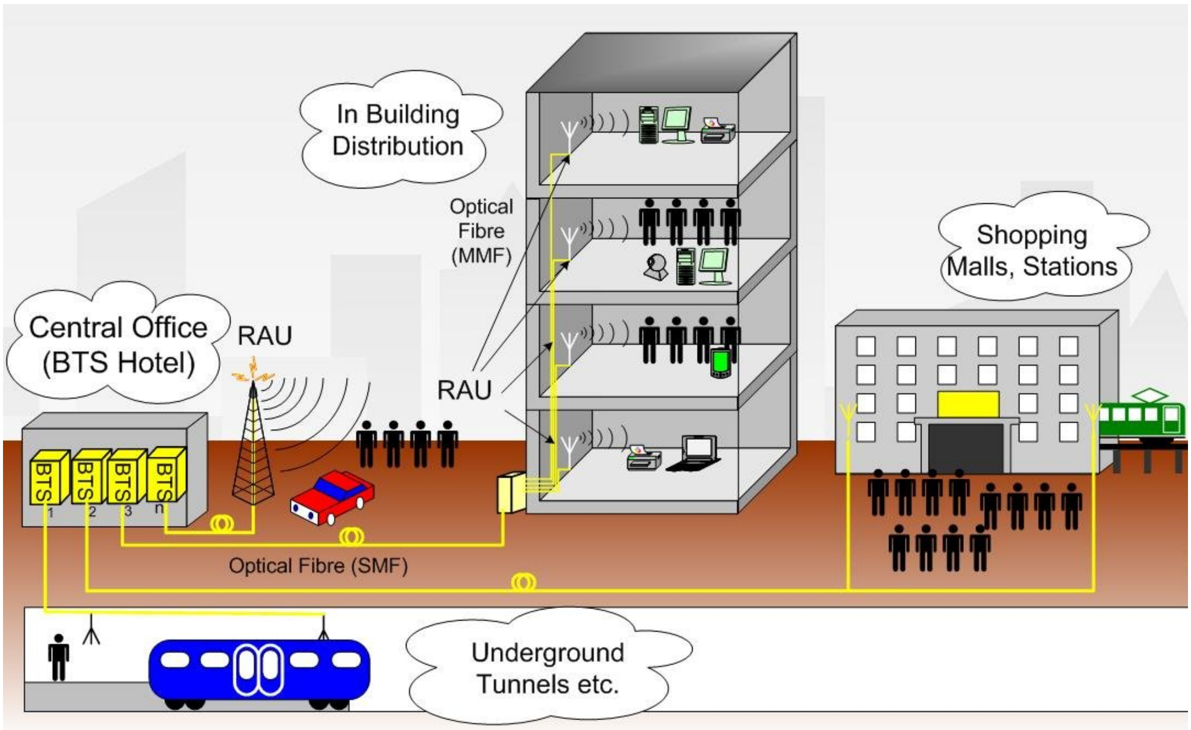

Fig. 1: Demonstration of the applications of radio over fiber technologies which use a base station hotel to provide coverage both outdoor and in-building.

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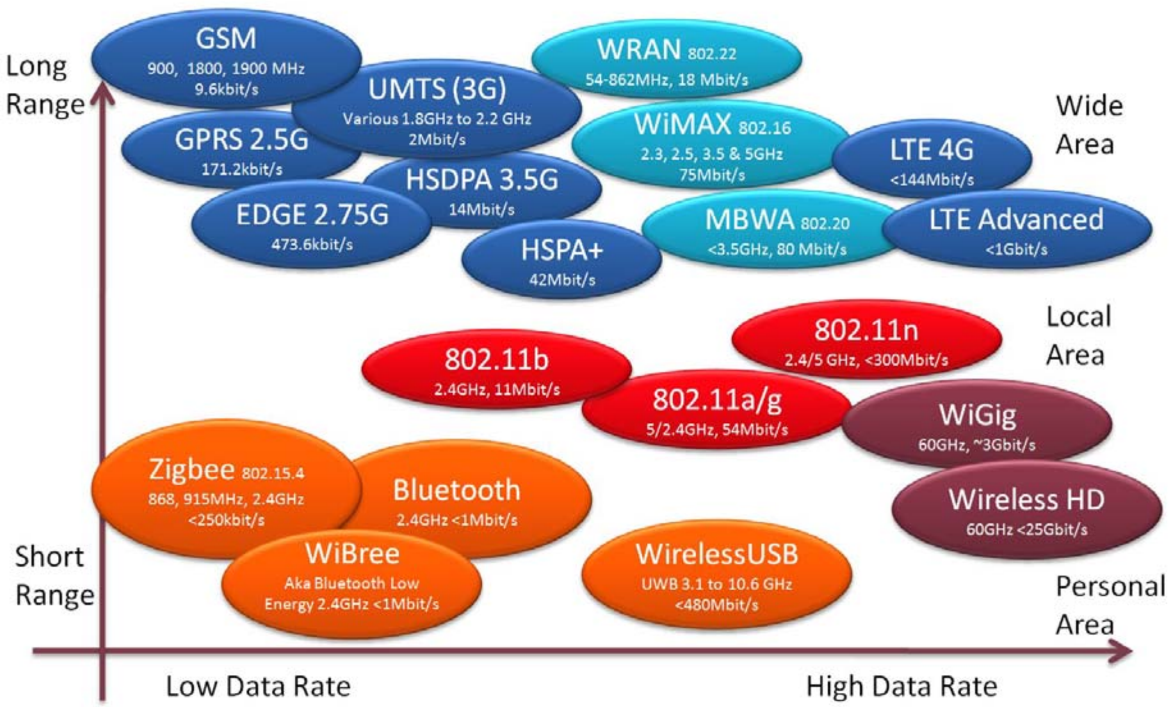

Fig. 2: Summary of wireless standards

network is deployed. Increasing the end user bandwidth also mandates the upgrade of the backhaul infrastructure to support the high number of wide-bandwidth base-stations. Here we will discuss in detail how radio over fiber technologies may address these challenges and identify what issues are being investigated and what further challenges remain if radio over fibre is to act as a key enabler for broadband radio networks.

Support for wireless standards

The concept of a radio over fibre network is as a ‘transparent’ (or as near as possible) transport network to distribute radio signals to the required remote access units (RAUs). Therefore, much of the specification in a radio over fibre network design is based on the wireless standards which are continually being developed and updated. Figure 2 illustrates just some of the range of standards that are currently in use or being developed. They cover a wide range of frequency bands from the VHF bands through to 60GHz. Historically they have been fairly narrow band (10s of MHz at most), however, newer developments such as Ultra Wide Band[6] (one flavor of which is being marketed as WirelessUSB) requires significantly wider bandwidths of the order of 7.5GHz (from 3.1GHz to 10.6GHz). This presents considerable challenges, most notably in broadband device design.

One of the most prevalent modulation formats to emerge in recent years is OFDM[7] which is used in, amongst others, 802.11a/g, WiMAX and LTE. It is well known that OFDM requires high-linearity which can be an issue in optical components[8]. Also emerging are the new IEEE 802.20 – Mobile Broadband Wireless Access (MBWA) and IEEE 802.22 – Wireless Regional Area Networks radio standards. The first provides for high bandwidth and high mobility applications in the frequency bands below 3.5GHz while the second implements cognitive radio schemes to make use of white space in the TV transmission bands to serve dispersed communities.

Although the affect that the introduction of optical transmission has on the physical layer radio standards has been well studied, the impact on the Media Access and Control (MAC) layer has received considerably less coverage. The most pertinent issue is the additional delay introduced by the optical fibre (approximately 4µS per 1km of fibre). In the MAC layer time-outs are used to ensure that in the event of corrupted or lost packets the system does not wait indefinitely. They are often specified as minimum periods in the standard and set to reflect the typical wireless propagation distances that are encountered in a particular system.

An example of the potential problems is demonstrated in the two-way handshaking technique used by the WiFi (IEEE802.11) standard. This is shown in figure 3 where we see that when the source station sends a data packet a count-down timer is initiated which expires after a period known as the ACK_Timeout. While the counter is active the data packet has to propagate through whatever medium is in the link, which in a radio over fibre system will include both wireless and optical elements. The packet is then received by the destination station which responds by sending an Acknowledgement packet (ACK) if there has been no corruption. This returns through the same wireless and optical link to the source station. The time for this to occur is known as the round trip time (RTT). If the ACK_Timeout expires before the correct reception of the ACK frame (i.e. ACK_Timeout < RTT) the source station will assume that the frame is lost and retransmit the data packet. If TCP is used as the transport protocol then this will occur for both data packets and the TCP acknowledge packets which are a second layer of acknowledgement.

It is easy to see that the increased waiting period due to fibre delay causes a degradation of the total throughput in the system. It has been shown that in an 802.11b link (11 Mbps, Basic Access) for example, the throughput decreases gradually from 4.7 Mbps when no fibre is present to 4.3 Mbps over 11 km of fibre (9% drop)[9]. However, assuming a typical timeout of 450μS, we see a complete breakdown in communication once the fibre length in the system exceeds 11 km as the system's round-trip delay exceeds the ACK_Timeout value.

Novel Optical Components

To fully keep pace with the developments in the radio standards described above, both in terms of bandwidth and carrier frequency, the development of new components is vital. In addition, strategies to reduce the cost of the components used, particularly those in the cost sensitive remote antenna unit (RAU) are need, either through improved design or clever reuse of existing components[10]. Of special interest are the developments in vertical cavity surface emitting lasers (VCSELs) technology which are producing devices suitable for high bandwidth modulation and operating at longer wavelengths[11].

Also of interest are devices that can operate as both a detector and modulator of optical signals. One such device is the asymmetric Fabry-Pérot modulator/detector (APFM)[12] which have been demonstrated for real applications and have the potential of significantly cost reduction in deployed systems. Increased integration of devices is another avenue being explored to reduce cost with recent devices including integrated mode-locked lasers operating in the 60GHz band[13] or the integration of optical devices operating in microwave bands (such as an APFM) with antennas[14].

Also of importance is the linearity of the optical link which is usually dominated by the electrical to optical conversion stage. For typical radio signals the linearity requirement is considerably higher than that required in digital systems with spurious-free dynamic ranges (SFDR) of >100 dB.Hz$^{2/3}$ required in some standards. A number of techniques have been developed that improve inherent linearity by better design of the devices[15] or that make use of compensation techniques such as feed-forward linearization to compensation for degradation caused by the use of low-cost components[16]

A question that is often asked of radio-over-fibre engineers is "Will we see a truly broadband RAU which covers multiple bands?". This would facilitate the distribution of multiple wireless bands without replicating many parts of the chain for different bands. Within the optical link components are commonly produced with wide bandwidths for digital applications, although, as discussed previously, some improvement in linearity for analogue applications is still required. In the electrical chain and in particular in the area of broadband antennas there are still great challenges although the move to higher bands, where the fractional bandwidth requirement for even very broadband signals is much lower presents significant opportunities.

Low-Cost Architectures

Until recently much of the research in the area of radio-over-fibre systems was dominated by the development of novel components and the investigation of the performance limits of point-to-point links. However, to get maximum benefit, with minimum cost radio-over-fibre networks must be developed which follow the trends of baseband optical access networks, including the development of point-to-multipoint networks.

These architectures must seek to minimise the component count while offering the flexibility discussed in the next section. A number of interesting new research directions have emerged in this area, in some cases enabled by the commercial development of new components. For example systems are currently being developed using Reflective SOA devices, which enable low-cost and non-wavelength specific RAU devices to be deployed[17]. Other potential techniques include the use of ring architectures where the signal at an intermediate frequency (IF) and an RF carrier are distributed to all end points. This has been demonstrated within a system where a 37.6-GHz

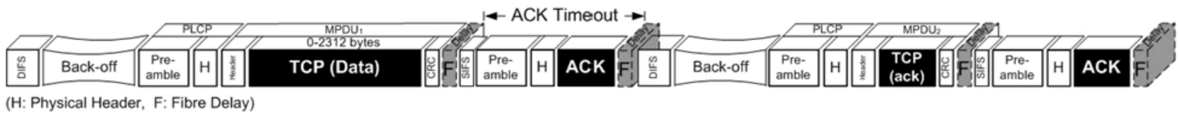

Fig. 2: The effect of fibre delay on TCP traffic in a Radio over fibre Network.

carrier is distributed around a CWDM ring with a number of QPSK data signals[18].

Networking

The use of radio over fibre in distributed antenna systems (DAS), to shift the electronic processing away from the antenna site into a central location, opens up new networking opportunities that have not yet been fully exploited. This shift in equipment location means that capacity can now be reallocated to any location in the network, rather than be fixed by the equipment that is installed in a particular base-station site as the allocation of additional frequencies is conditioned not by the available equipment but by the mapping of frequencies to fibres. If such a network where to be implemented dynamic bandwidth allocation schemes become feasible whereby capacity can be moved around the network to follow traffic densities and users demands[19].

There are however a large number of open issues that require designers to take a holistic and cross layer view of the network. This mandates a vertically integrated network that considers the interactions between routing and control at all layers. It will require routing and MAC protocols that understand that there are multiple layers to the network. For example from any one end point (i.e. a user's wireless device) there will be a wireless physical layer and a wireless MAC layer which allows sharing of the available spectrum but there will also be an optical MAC layer to allow sharing of the optical media which may be a PON type structure[20]. Frequency reuse plans that are typically static will have to become dynamic and consider mappings of frequencies to wavelengths to fibres. Also handover mechanisms will need to be developed to allow the capacity allocation algorithms to reconfigure the network.

Conclusions

This presentation reviews the current state of the art in radio over fibre technologies and networks and discusses some of the key challenges that face researchers in this area. It is argued that if radio-over-fibre techniques are to be deployment to support future high bandwidth mobile and fixed radio networks four main areas need to be addressed; meeting the requirements new radio standards, novel optical components, low-cost architectures and networking strategies.

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