HIGH CAPACITY OPTICAL FIBRE BACKBONE NETWORKS FOR MILLIMETRE-WAVE FIBRE-RADIO SYSTEMS

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ABSTRACT:

Millimetre-wave frequencies have been explored around the world for the provision of broadband wireless services via wireless access networks. Optical fibre backbones have emerged as a cost-effective way of interconnecting remote base-stations with a central office in such network architectures. By incorporating wavelength division multiplexing in conjunction with rf-over-fibre signal transport, a high capacity network with simple and cost-effective base-stations can be realised. In this paper, we discuss the technologies that will help to achieve high capacity optical fibre-backbones suited for millimetre-wave rf-over-fibre signal transportation.

INTRODUCTION

Millimetre-wave (mm-wave) frequency bands (between 26 -100 GHz) have been investigated around the world to offer truly broadband services to users by utilising the enormous bandwidth available within this spectrum. By taking the advantage of higher propagation losses and the efficient frequency re-use at mm-wave frequencies, pico- or micro-cellular network architectures that can offer broadband wireless services can be realised. In such networks, the total capacity of an antenna base-station (BS) will be of the order of 1-2 Gb/s and due to the smaller cell sizes; there will be a large number of BSs in the network. One of the technical challenges in the implementation of such networks lies in the design of low cost BSs as well as the provision of a backbone network to interconnect multiple BSs with the central office (CO) where switching and routing functions are performed [1]. An optical fibre feed with an rf-over-fibre architecture where the signal is distributed to and from the BS as a mm-wave modulated optical signal [2], has the advantage of simplifying the BS design. However the performance may be severely limited by fibre chromatic dispersion [3] although this can be overcome by using optical signal sideband with carrier (OSSB+C) modulation [4]. Due to line-of-sight constraints of radio signals at mm-wave frequencies, a sectorised antenna interface is required at the antenna BS [5]. Each sector may be fed by a different optical signal depending on the application. Such an approach is simplified by incorporating wavelength division multiplexing (WDM) technology. In these WDM systems with standard wavelength grid spacings of either 50 GHz or 100 GHz, a WDM channel wavelength will be modulated in OSSB+C format with an rf signal at a mm-wave frequency (with an information bandwidth of 1-2 GHz) and transported over fibre. However, such systems utilising 50 or 100 GHz of optical bandwidth to transport a total of only 1-2 Gb/s throughput will ultimately exhibit poor optical spectral efficiency.

Wavelength interleaving allows the optical network to achieve a spectral efficiency greater than WDM systems based on standard wavelength channel spacings of 50 or 100 GHz [6,7]. Multiple wavelengths with OSSB+C modulation are multiplexed in such a way that the optical channel frequency separation between the adjacent wavelength channels is less than the modulation frequency. For example, a 38 GHz fibre-radio link might use an optical channel frequency separation of 22-26 GHz to achieve wavelength interleaving. The desired optical carrier at the specified wavelength and the corresponding optical sideband can be then recovered using a wavelength-interleaved optical add-drop multiplexer (WI-OADM). In this paper, we discuss the wavelength interleaving technique and the proposed WI-OADM architectures based on fibre-Bragg grating devices. In addition, network capacity in such wavelength interleaved fibre-backbone networks is discussed in terms of the number of wavelength channels that can be supported.

WAVELENGTH INTERLEAVED FIBRE-RADIO NETWORKS

Fig. 1 shows a schematic of a mm-wave WDM fibre-radio network incorporating OSSB+C modulation and a novel wavelength-interleaving (WI) technique to increase spectral efficiency [6,7]. The multiple WDM channels (λ_1, λ_2, …) and their corresponding optical single sidebands (s_1, s_2, …) originating at the central office (CO) are multiplexed together via a wavelength-interleaved multiplexer (WI-MUX). Wavelength interleaving, as shown in the inset of Fig. 1, allows the optical network to achieve a spectral efficiency greater than WDM systems based on standard wavelength channel spacings of 50 GHz or 100 GHz [eletters]. The interleaved channels are then transported via an optical fibre network to remote nodes (RN) feeding a particular antenna BS. The RN selects the optical carrier at the specified wavelength and the corresponding optical sideband using a WI-OADM. The upstream radio signals are carried by a WDM channel at the same wavelength and inserted back into the network via the same WI-OADM.

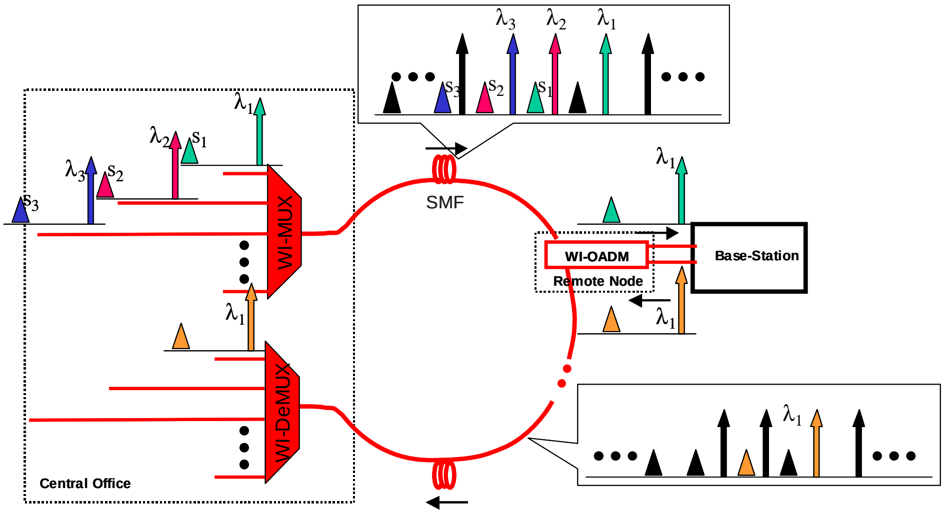

Fig.1 Wavelength interleaved fibre radio network

Such WI-OADM can be realised by incorporating fibre-Bragg gratings (FBGs) in conjunction with optical circulators as shown in Fig. 2 [8]. Three WDM carriers (λ_1-λ_3) are interleaved with their corresponding optical sidebands s_1-s_3 respectively. The interleaved optical signal was passed through the first circulator to a novel eight phase-shifted grating. The multi-phase-shifted grating was used to obtain a particular transmission profile that will enable the optical carrier at λ_2 and its corresponding sideband s_2 to be reflected from the FBG and dropped at the first circulator's output port. The measured optical spectra obtained at various ports of the WI-OADM are also shown in Fig. 2 demonstrating the add-drop functionality. Other unwanted spectral components (λ_1, λ_3, s_1, s_3) are also visible in the drop port spectrum as a result of the slow rolloff in the FBG notches and small transmission amplitude ripples in the grating. The impact of these other unwanted spectral components is assessed via bit-error-rate (BER) measurements of the recovered data from s_2 and very negligible power penalties were observed [8] due to optical crosstalk arising out of imperfect transmission profile of the FBG filter. In addition, FBG transmission profile could be further optimised to lower the optical crosstalk characteristics [9].

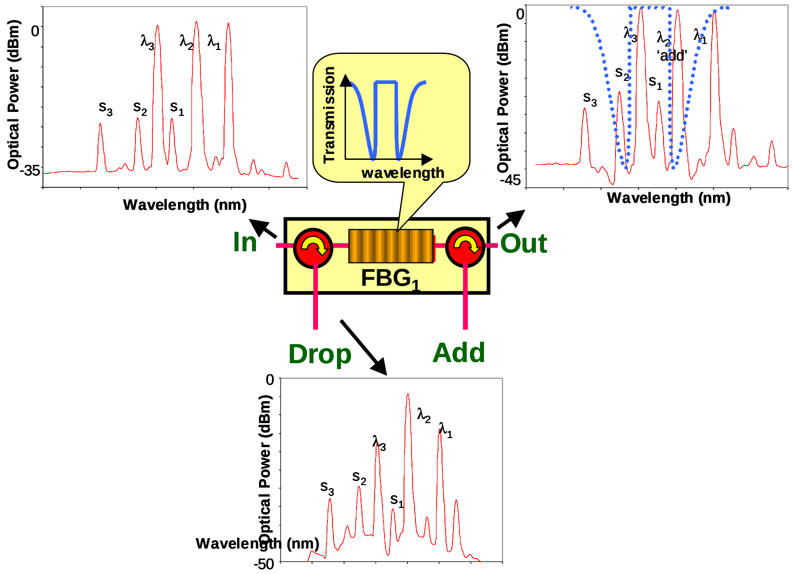

Fig.2 Wavelength interleaved optical add-drop multiplexer and its perfromance characteristics

CAPACITY OF WAVELENGTH INTERLEAVED FIBRE-RADIO NETWORKS

Fig. 3 shows a schematic diagram of a WDM fibre-radio backbone with primary ring architecture incorporating WI and OSSB+C modulation. The primary ring interconnects the CO to a number of RNs that are then connected to a secondary ring network linking the antenna BSs to the CO. At the CO, multiple WDM channels are multiplexed together and distributed to the RNs where a block containing a number of WDM channels are dropped before each of the WDM channel is routed to the designated BS. In the upstream path, WDM channel at the same wavelength as the dropped channel is added back into the network before they are routed back to the CO. To investigate the capacity improvements arising as a result of wavelength interleaving, we performed a simple link budget analysis for a range of network rollout scenarios with the WDM ring backbone architecture as shown in Figs 3a to 3d.

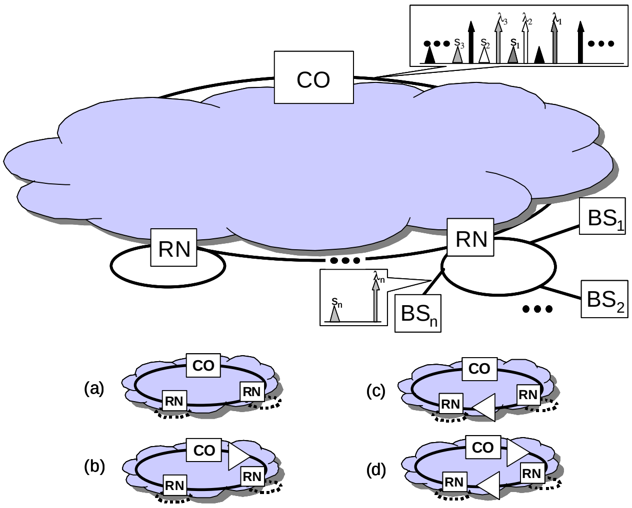

***Fig. 3** Schematic diagram of WDM fibre-radio ring architecture with various network layout scenarios (a)passive network,(b) pre-amplification at CO, (c) mid-span amplification and (d) pre and mid-span amplification*

Assuming a modulation frequency of 36 GHz and the EDFA gain bandwidth of 30 nm, a total of 52 WDM channels can be incorporated without wavelength interleaving and this capacity can be extended to 156 channels if these channels are interleaved at a frequency spacing of 24 GHz. However due to limited link efficiency for the transportation of mm-wave modulated optical signals, passive network as shown in Fig 3a becomes less feasible and an amplified optical link may be essential for a more practical and realistic ring length (primary ring length of ~100 km and secondary ring length of ~10km). When the optical amplifier is placed at the CO (Fig. 3b) for cost effectiveness, the performance of such layout may be compromised by amplifier and fibre nonlinearities as shown in Fig 4a that summarises performance of the last RN in the network. When the optical amplifier is placed in the middle of the ring (Fig. 3c), the signal performance for the last node can then be enhanced as shown in Fig 4b. However, the BER contours received at RN2 (before optical amplification) as shown in Fig. 4c indicates that the network now requires a channel power of at least +11 dBm to achieve a BER = 10^{-9} independent of the total network capacity highlighting the need for optical amplification at the CO as well as at the mid-span as shown Fig 3d. However, the level of amplification required at the mid-span can be lowered as illustrated in Fig. 4d. To achieve the maximum capacity, a mid-span gain of 10 dB or higher would be sufficient.

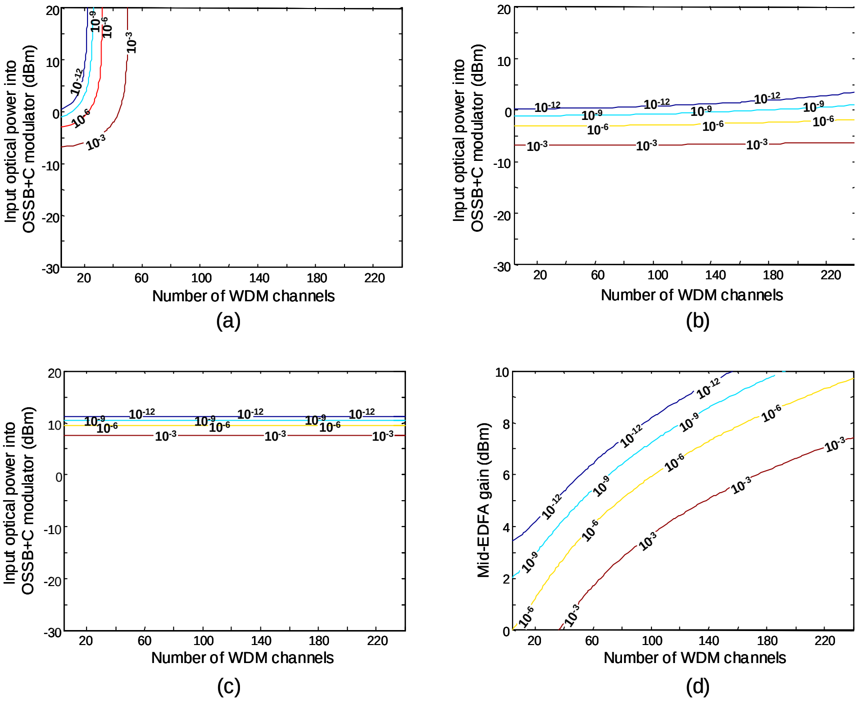

***Fig. 4** BER contours for (a) pre-amplification (b) mid-amplification (RN4) (c) mid-amplification (RN2) (d) pre-and mid-amplification network layouts*

CONCLUSIONS

Optical fibre backbones have emerged as a cost-effective way of interconnecting remote base-stations with a central office in broadband wireless access networks operating at mm-wave frequencies. By incorporating wavelength division multiplexing in conjunction with rf-over-fibre signal transport, a high capacity network with simple and cost-effective base-stations can be realised. We have shown how wavelength interleaving can be incorporated to significantly increase the capacity of the backbone network by improving the optical spectral efficiency of the rf-over fibre transportation technique. We have also demonstrated a novel wavelength interleaved optical add-drop multiplexer based on novel fibre-Bragg grating filters suitable for such networks. Different network topologies of such wavelength interleaved network were considered and capacity predictions based on a simple link budget analysis were presented.

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