System architecture for fibre-fed WDM/SCM pico-cellular broadband mobile networks

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Abstract – A network architecture for future fibre-fed Mobile Broadband Systems (MBS) employing WDM, SCM and space switching for signal assignment to particular antenna units is described. The proposed network architecture is simulated using VPI Systems software, with realistic component values used. The simulation results demonstrate the feasibility of the proposed architecture for pico-cellular networks.

1. Introduction

The converging requirements for subscriber mobility and high information bandwidths have led to the formulation of proposals for Mobile Broadband Systems (MBS). These systems will use millimetre-wave frequencies and pico-cells. The numerous pico-cells, acting as overlays for the lower bandwidth existing networks, will provide broadband services to subscribers. However, there is then a requirement for the antenna units in these cells to be inexpensive. A number of network architectures have been proposed, ranging from millimetre-wave signal generation in a central site with fibre distribution to the cells [1], to data signal distribution prior to millimetre-wave LO generation (directly or with multiplication) and up-conversion at the antenna unit [2]. In this work, an intermediate scenario is examined, where a millimetre-wave reference frequency is distributed to each antenna unit, together with data on an IF (RF/microwave) subcarrier on a different wavelength. The basic architecture has been proposed for use with an antenna unit module described in [3]. In this work, the proposal is extended to demonstrate how the architecture allows for individual antenna units to be addressed by the central master station using a combination of WDM and SCM. The feasibility of the architecture is then demonstrated by simulation of a network using realistic components using the VPI Systems software package.

In the basic architecture, a fibre-optic backbone networks feeds the antenna units from a central master station using a combination of WDM and SCM (figure 1). The transmit frequency of each base station is controlled from the master station. The data rate of the system will vary according to demand with a maximum of 155Mbps. Frequencies for transmission over the radio interface are around 60GHz and IF signals travelling from the master station to the antenna units have frequencies of around 2GHz. The architecture is described in more detail in the following section.

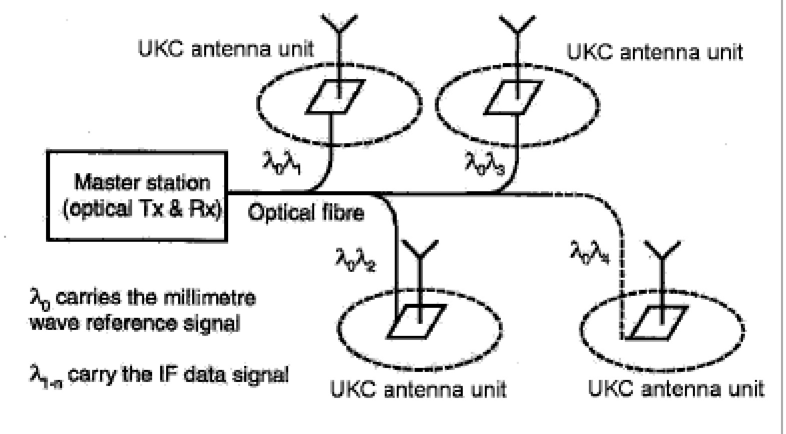

Figure 1 – UKC mm-wave over fibre general system architecture

2. Development of an Active Fibre Fed Mm-Wave Network Architecture

The basic system may be broken down into two different sections: (1) The central master station section which mainly contains the Base Transceiver Stations (figure 2); and (2) the coverage footprint section which is the geographical area covered by the central master station using the mm-wave over fibre links (figure 3). The coverage footprint itself can be broken down into three sub areas: (1) The central location of the coverage footprint, the area where optical signals corresponding to different regions are separated; (2) the central location of a particular region, where optical signals are transported to the appropriate antenna unit for transmission; and (3), the central location of the cells (the antenna units), where intermediate frequencies are converted to mm-wave frequencies and data is transmitted over the air interface.

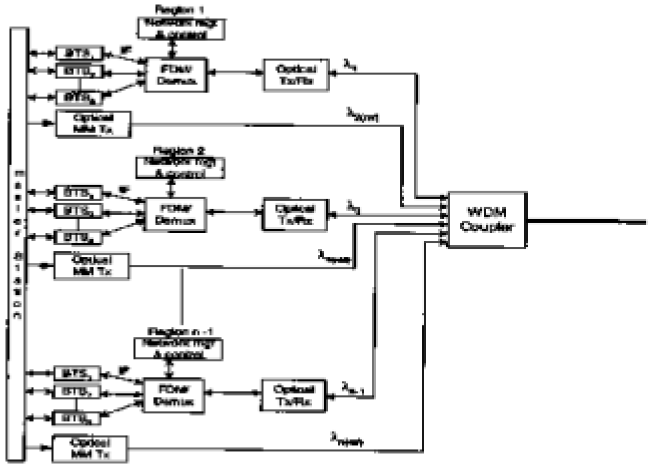

Figure 2 – Central master station

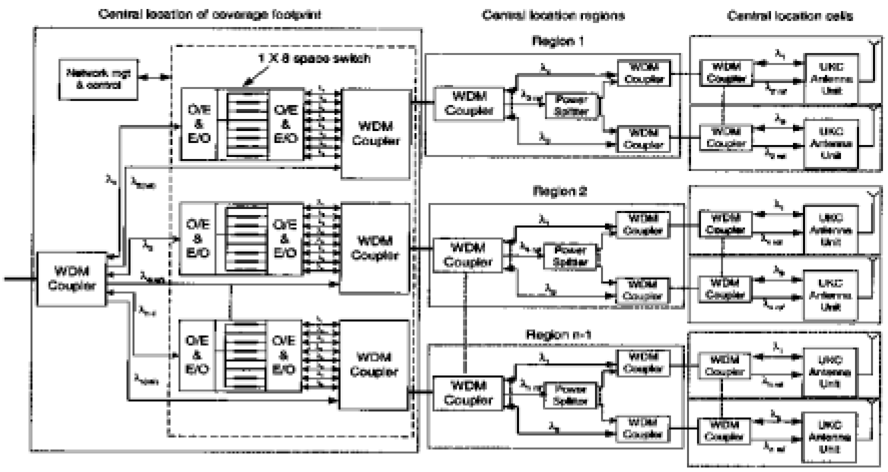

Figure 3 – Coverage footprint of MBS Network

The operating frequencies of the Base Transceiver Stations (BTS) and therefore of the antenna units are controlled by the master station. As it has already been stated the area to be covered by the master station is divided into a number of regions. There are then eight BTSs that correspond to the eight antenna units and pico-cells of a specific region. Signal transmission can be divided into two directions: Down-link and Up-link.

2.1 Down-link transmission

Intermediate frequencies from the BTSs are combined using FDM – SCM for our optical fibre system. Network control will not allow similar IF frequencies to be multiplexed. The composite signal is then mapped onto its own optical wavelength. There is also a millimetre wave reference signal generated at the master station with a frequency of around 60GHz. This reference signal will be used at the antenna unit for frequency up-conversion of the IF signal to RF. Signals on different optical wavelengths that are destined for all of the regions to be covered by the master station, along with the reference signal on its own wavelength, are transported via a WDM link to the central location of the coverage footprint (figure 3). At the coverage footprint there is a space switch present for each particular region. The space switch, controlled by network management, separates the IF signals according to destination. Optical-electrical and electrical-optical conversion is required as it is assumed that the space switching takes place in the electrical domain. After the switching, the signals are sent on different wavelengths via a WDM multiplexer to the central location of each region. At that point the reference signal is passed through a power splitter such as a star coupler so that it can be shared to all cells in a region. Each of the other wavelengths are then individually multiplexed with the mm-wave reference signal and transported to their associated antenna unit. At the antenna unit IF to mm-wave frequency conversion takes place followed by transmission to the subscriber station.

2.2 Up-link transmission

The mm-wave signal received by the antenna unit is down-converted to IF (using the millimetre-wave reference). This IF signal is then mapped onto its own wavelength and sent to the central location of the region and combined using WDM with signals from the other cells in the region. The composite signal is sent to the space switch of the central location of the coverage footprint. At that location, after WDM demultiplexing, optical to electrical conversion takes place, similarly to the down-link, with network management and control selecting the required output ports for the data-carrying IF signals. Then, the electrical signals for each region are combined using SCM on a single optical carrier. The composite signal and similar ones from different regions are then transported via a WDM link to the central master station where separation of the optical signals from the different regions takes place. Each optical signal is then sent to the particular set of BTSs for that region, and then each IF signal is allocated to its corresponding BTS where the original data is recovered.

3.Simulation

3.1 Model Development

The physical layer of the proposed MBS architecture was simulated to test operational characteristics using VPI™ systems software package. The system was designed by taking into consideration only one operating region and thus only one set of eight Base Stations was required. However appropriate coupling and de-coupling components were designed that could accommodate up to eight regions. The final design was simulated using the maximum MBS data rate of 155Mbps.

QPSK modulation scheme was chosen for data transmission. A sufficient channel frequency spacing of 400MHz was used for the results presented, although other spacings should be studied. The reference millimetre wave signal is generated using an external Mach-Zehnder modulator as a frequency doubler [1].

Through the simulations we investigate the physical layer performance and so a simple space switch model that accommodated optical to electrical and electrical to optical transformations in order to take into consideration possible losses from the various components was used. Both the up-conversion and down-conversion processes at the antenna unit and within the subscriber station are achieved by multiplication of the IF signal with the mm-wave reference signal. Of the two frequency components generated for the radio link (with values: ~60GHz +/- IF frequency) one is filtered out to achieve more efficient use of the available spectrum. As the central master station is completely separated from the remaining network it is assumed 25km of standard single mode fibre connects the master station with the central location of the coverage footprint. The length of the optical fibre connecting the centre of the coverage footprint with the centre of a region is assumed 1km long. As pico-cells have a small diameter, the fibre connecting the antenna unit with the centre of its corresponding region is assumed 100m long.

3.2 System Performance

Minimum values for transmitted and received power by the subscriber station that would allow proper recovery of the original data are used. The Path-loss (P.L.) over the radio link is calculated using (1):

$$\text{P.L.} = (4^*\pi^*d/\lambda)^2 \qquad (1)$$

where d is the radius of the pico-cell and λ is the wavelength of the particular transmitted mm-wave. For the proposed network a maximum of 90dB path-loss can be tolerated before thermal noise prevents the achievement of an appropriate Bit Error Rate (BER). From (1) this corresponds to a pico-cell with a diameter of 25.17m. Worst-case realistic loss values for the losses of filters, couplers/de-couplers, optical receiving and transmitting components have been taken into account. Also fibre attenuation and splice losses and component connection losses were modelled in the system. Excess noise was added at the electrical amplifiers used according to their particular noise figure. Thermal noise power for the receivers, the mixers used for up and down-conversion of the IF to mm-wave frequencies and vice-versa and the laser driver components was added.

With path-loss, noise and loss values being taken into consideration and assuming that the antennas in both directions have a combined gain of around 6dB we conclude the following: For the down-link system the minimum transmitted power from the base station is –2dBm and as a result the received power at the subscriber's station is –87dBm. On the other hand, the transmission power from the subscriber station at the up-link is around 0dBm. The power received by the antenna unit is –84dBm. The transmitted power values required are lower than those proposed by the IEEE standards related to air interface for fixed broadband wireless access systems [4]. The eye diagrams in Figure 4 show the quality of the signals for the proposed network, with a downlink BER of 1.59×10^{-7}, and an uplink BER of 8.35×10^{-6}.

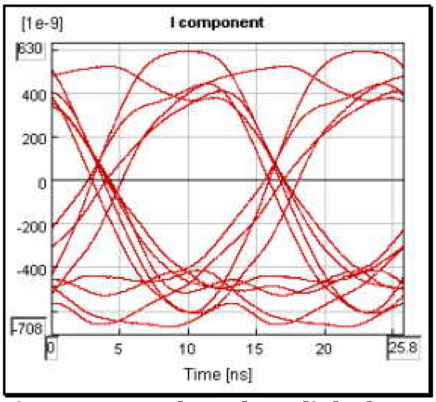

Figure 4a – In-phase down-link channel

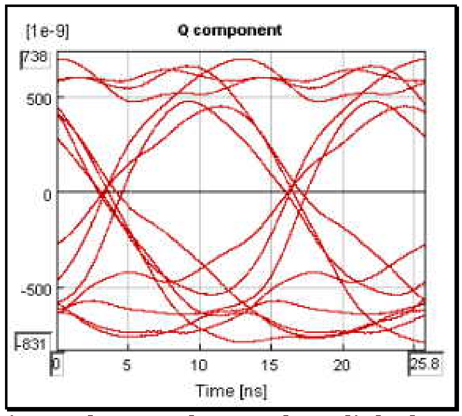

Figure 4b – Quadrature down-link channel

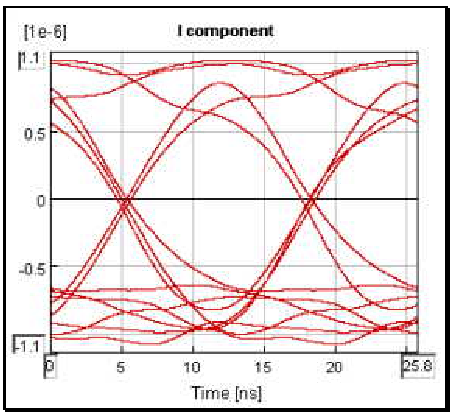

Figure 4c – In-phase up-link channel

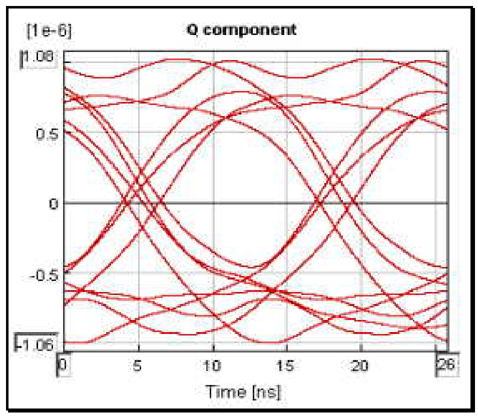

Figure 4d – Quadrature up-link channel

4.Summary

This paper has presented and analysed a fibre-fed MBS network architecture combining WDM, SCM and space switching to address numerous pico-cellular antenna units from a single central master station. It was demonstrated through simulation that sufficient Bit Error Rate can be achieved for a physical layer using current component technology. Future work will examine the performance of modified network architectures [5] which eliminate the need for space switches.

5.References

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