White Paper

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Wavelength Division Multiplation Technologies for UMTS Radio Coverage Extension by using the Radio-Over-Fiber Technique

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Introduction

The arrival of UMTS raises a series of technical, economic, and administrative questions for license-holding operators who must allocate investment monies to set up a network that meets broad coverage objectives with speed and flexibility. Several complex elements have to be taken into account, among them size of the equipment, the need for more sites when compared with GSM, and the growing costs and issues of equipment availability because of the limited capacity of network manufacturers to quickly respond to market demand. This paper addresses these issues by offering a technological and systems science application, which, among other things, provides the basis for potentially dividing up investment costs among new players into the value chain. The solution consists of a vendor-independent multicellular distributed fiber optic platform optimized for UMTS. The system, which can be inserted into a single- or multi-operator context, offers a high degree of flexibility and modularity as well as enables the investor to move in gradual steps and dynamically bring forward the breakeven point.

Basic Technology for RoF Applications

It is well known that the RoF (Radio over Fiber) technology takes advantage of the very low attenuation exhibited by optical fiber. Particularly, Single Mode Fiber (SMF) provides low attenuation values in a broad range of wavelengths. The bandwidth in which SMF provides these values is far wider than any other transmission medium.

RoF technology is based on the analog Intensity Modulation (IM) of a semiconductor laser source and its demodulation through Direct Detection (DD) performed by a PIN photodiode [1, 2] at the other end of the optical fiber connection. The semiconductor laser source typically operates in the wavelength bands centered around 1310 nm and 1550 nm, in which attenuation of the fiber is at minimum relative values.

IM could be achieved by using Direct Modulation of the bias current or External Modulation of the optical intensity of a laser device. For DD, the most used solution is based on a PIN (Positive-Intrinsic-Negative: a type of semiconductor material used to allow wideband characteristics) InGaAs photodiode [1, 2]. The bandwidth of the connections is in the range of several GHz, depending on the technology used for the Electro-Optic transducers. It ranges from 2 to 3 GHz for an RoF link equipped with a cheaper MQW-FP laser to up to 50 GHz for very high speed modulator and microwave InGaAs PIN photodiode.

Generally speaking, the optical link suitable for RoF applications is an analog link with an electrical bandwidth adequate for the bandwidth of the RF signals and particular requirements of the RF signal dynamic range, summarized in the Spurious Free Dynamic Range (SFDR) [3]. This parameter is defined as the level difference in dB between the carrier's output level and the noise level in which the Intermodulation Distortion (IMD3) products, generated by the intrinsic third order non-linearity of the link, are at the edge of the noise level (Figure 1).

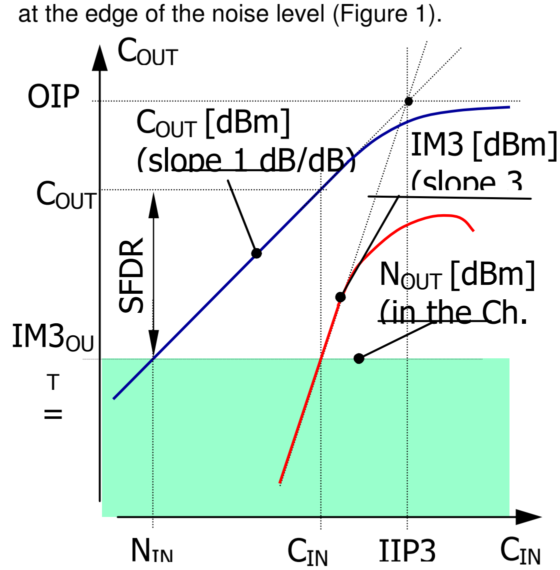

Figure 1 - Spurious Free Dynamic Range (SFDR) Definition

The following equation defines the SFDR:

$$SFDR = \frac{2}{3}(OIP3 - N_{OUT})$$

In the equation, OIP3 is the Output Third Order Intercept Point and is defined as the theoretical point at which, if there is no gain compression, the IM3 output of the third order intermodulation products would be equal to the output level of both RF carriers. This parameter summarizes the capability of a linear RF device to operate in a multi-carrier environment. N_{OUT} is the available output noise power levels, expressed in dBm, measured in the band of the signals.

SFDR requirements are strictly dependent on the specific wireless application. For the optical links dedicated to remote radio coverage, the SFDR is in the range of 70 to 80 dB, when computed in 200 kHz of bandwidth.

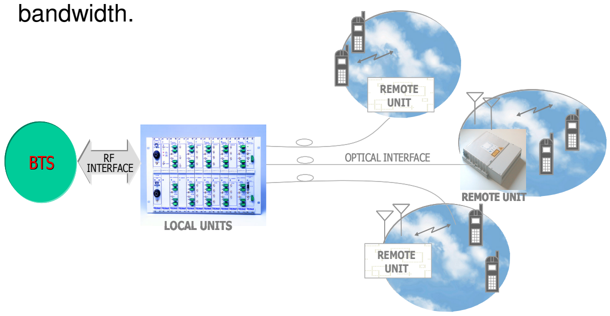

Figure 2 - Typical RoF Wireless Coverage Extension

In Figure 2, the basic application of RoF technique intended for wireless coverage extension is depicted. The Local Unit converts the downlink (DL) – base to mobile direction – multi-carrier RF signal generated from a Base Transceiver Station (BTS) into an IM optical signal. The optical signal is distributed through fiber connections to each Remote Unit where the photo-detection process allows conversion to the RF domain. Then the RF level is amplified and adjusted according to the system design plan and radiated by the coverage antenna. For the uplink (UL) path (mobile to base direction), the same operation is done in reverse by using a parallel IM optical signal and fiber connection.

DWDM and CWDM RoF Solution

The availability of basic DWDM (Dense Wavelength Division Multiplexing) and CWDM (Coarse Wavelength Division Multiplexing) technologies has enabled design of a systems solution that is ideal for third generation wireless networks. The increasing availability of optical fiber lines in urban telecommunication networks – incumbent telecom networks, telecom and datacom networks, and civil networks – makes optical fiber an attractive and practical system for distribution of micro- and pico-cellular UMTS. Both the DWDM and CWDM technologies enable reuse of each optical fiber link. The application exploits the standard single-mode ITU-T G.652 fiber, which can be shared with other services present in other “windows” or transmission bands.

This technique allows concentration of network devices in so-called “Node B hubs,” where coverage and capacity are flexibly distributed via fiber optics to “remote nodes” (Figure 3), which include equipment and coverage antennas with extremely low visual and electromagnetic impact.

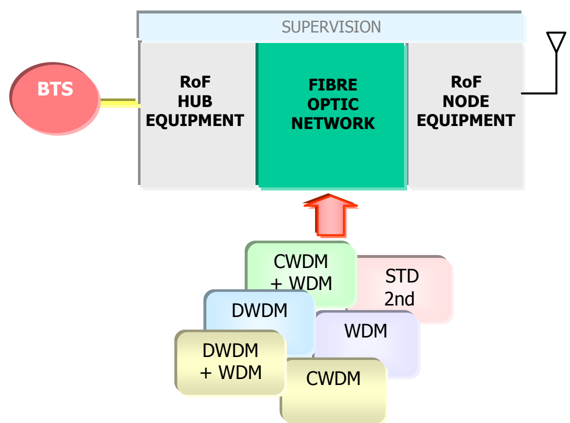

Figure 3 - Adding xWDM to the RoF application

The system can be designed for use with star fiber networks (cable TV) or ring networks (telecom). Its distinguishing feature is the unambiguous color-node association enabling “spatial selectivity” or, in other words, the possibility of sending different signals to different nodes of the optical network to segment the area of coverage down to the level of a single microcell. Planning and routing of the segments takes place in the centralized base station site, where there are clear advantages in terms of flexibility and network efficiency.

Spatial selectivity is done by using the optical drop-before-add technique in each node of the network. The wavelengths associated with the node are extracted in the DL direction and then inserted in the opposite UL direction by using Optical Add and Drop (OADM) filters.

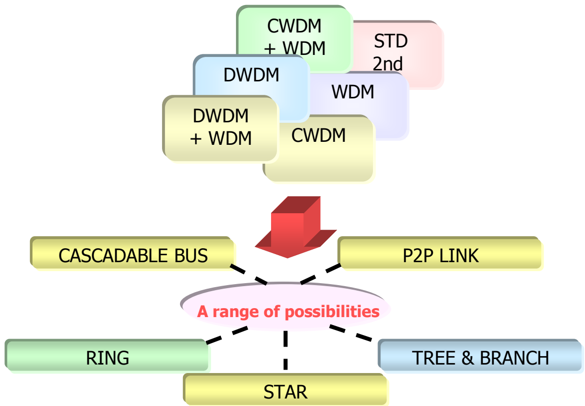

Figure 4 - The range of xWDM RoF solution.

An OADM filter gives the flexibility to design several network architectures, all shown in Figure 4. When this operation is conducted at the same optical frequency, it enables optical frequency re-use.

The possible use of a “double ring” structure offers further advantages in terms of redundancy and radio performance improvements, thanks to the possibility of diverse reception fundamentals in UMTS WCDMA technology.

Applying the DWDM concept to an RoF application, the first requirement relates to the optical transmitter and, particularly, the availability of laser sources for direct modulation on the ITU-T grid, suitable for analog application. Since each RoF system needs several optical transmitters, one or two for each wavelength, a solution based on an external modulator is unattractive because of price. These devices are based on an expensive Mach-Zehnder lithium niobate optical intensity modulator and that also require many additional electronics. Today, several laser manufacturers provide high power (up to 10–13 dBm) MQW-DFB analog lasers suitable for DWDM applications at an affordable price.

Regarding MUX, DEMUX, and OADM devices, special requirements have to be specified for Insertion Loss (IL) and channel isolation. Obviously, to save the optical budget, the IL of each device on the network must be at the lowest level. Secondly, special care must be given to specifying the isolation requirement of the DEMUX and, in general, for each OADM filter placed before an optical receiver. This feature is not important for the MUX, as it acts as a combiner. Channel isolation, strictly related to the selectivity of the optical filter, gives the ratio of the optical power at the wanted optical frequency to the total amount of optical power coming from other optical frequencies. Since each optical channel traveling on the fiber is carrying its RF UMTS signal, any interference is carried out by the opto-electric conversion in each optical receiver. Finally, the isolation specification for optical filters in an RoF application must be carefully defined for the allowed level of interference (as per 3GPP standard).

Optical amplification is also possible in a DWDM system intended for RoF applications. The Erbium Doped Fiber Amplifier (EDFA) represents the most suitable solution for optical regeneration. However, Amplified Spontaneous Emission (ASE) radiation, always present in the optical spectrum at the output port of this type of device, represents a strong noise source that is converted to RF noise by the photodiode at the optical receiver. By choosing a proper EDFA design, the ASE power levels can be reduced to minimum. In this way, this technology can be used for optical regeneration, thus restoring the optical budget without affecting the RF performance of each link.

The Andrew DWDM solution is based on transmission along a single fiber of 8 wavelengths, which corresponds to the same number of “nodes” or UMTS microcells. The diagram in Figure 5 shows the structure of the system in a double ring with 8 nodes. The fiber-radio devices of each node use the drop-before-add technique. The color associated with the node is extracted in the base-to-mobile direction and then reinserted in the mobile-to-base direction by the OADM. RF signals corresponding to the two transmitting directions are then each routed to the user and to the network by means of appropriate power amplification required by the radio coverage.

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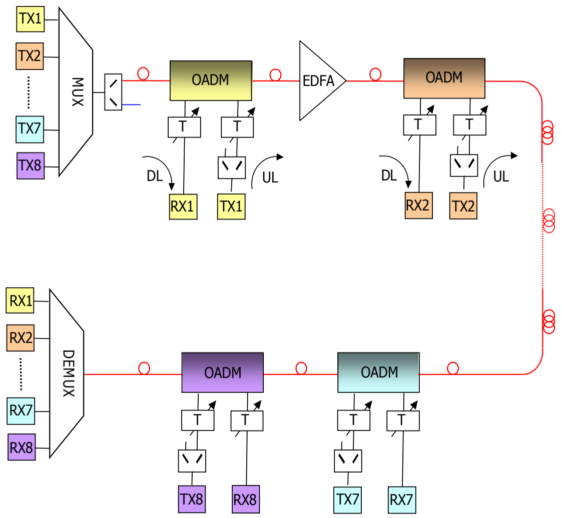

Figure 5 - The Optical Layer Double Fiber Ring

The transmission RF power of the microcells can be between 100 mW and 1 W, depending on coverage planning requirements. These levels enable reduction in height of the coverage antennas, with significant advantages in terms of network efficiency in an urban context, while at the same time keeping the electromagnetic field within the strictest anticipated limit, allowing a greater protection of the environment and public health. Because it is based on a lower cost, uncooled, low power (about +3 dBm) MQW-DFB laser device, the application of CWDM technology to RoF is limited by the optical budget. Moreover, the optical budget cannot be restored by EDFA technology. At the same time, optical filters are less performance demanding because of the wide range of pass band bandwidth. In keeping with these constraints, CWDM technology is cheaper when compared with DWDM and, even with this limitation, should be considered an economical choice when compared with DWDM for those applications not requiring a high optical budget.

Conclusion

It has been demonstrated that urban coverage distributed through DWDM and CWDM fiber-radio micro- and pico-cells offers numerous advantages when setting up Node B sites. Selective routing toward coverage areas corresponds to the microcellular nodes. Centralized administration allows flexible planning of a UMTS network with a gradual increase in capacity through progressive segmentation down to the microcellular level in relation to growth in the number of users and speed of the services offered.

Tables 1, 2, and 3 summarize and classify the features and benefits of this technology.

References

1 H. Al-Raweshidy, S. Komaki, "Radio over Fiber Technologies" Artech House Publishers, 2002.
2 "RF and Microwave Fiber-Optic Design Guide" Application Note, Agere Systems, April 2001.
3 J.C. Fan, C.L. Lu, L.G. Kazovsky, "Dynamic Range Requirements for Microcellular Personal Communication System Using Analog Fiber-Optic Links," IEEE TRANS. on MW Theory and Techniques, vol. 45, no. 8, August 1997.

TECHNICAL ASPECTS	
Features	**Benefits**
Coverage in line-of-sight, obtained thanks to a reduction in cell radius	•Optimum network and speed performance •Power control efficiency •Reduction in macro-micro interference •Quality of the service
Minimization of the soft handoff	•Maximization of traffic volume
Planning flexibility	•Progressive adaptation to traffic demand •Migration from a macro coverage •Distribution of a single sector to a micro coverage (segmentalization) without having to act on the distributed sites
Modular expansion	•Progressive adaptation to the demand for coverage
Redundancy and resilience	•Reliability and quality of the service
Network equipment centralized in BTS Hotels	•Optimal use of the interconnecting network

Table 1 - Technical Aspects

ECONOMIC ASPECTS	
Features	**Benefits**
Modular nature of the investment	•Dynamic optimisation of the breakeven point
Possibility of new Partners entering as "Coverage Providers"	•Dividing up of the investment •Outsourcing
Centralized and distributed structure with BTS Hotels / Remote nodes	•Possibility of co-siting with other existing services •Removal of the limitation "coverage/number of BTS" •Reduction of the administrative and maintenance costs of the sites •Reduction of the interconnection costs
Possible sharing of the system	•Spreading of the network running costs

Table 2 - Economic Aspects

GENERAL ASPECTS	
Features	**Benefits**
Centralized and distributed structure with BTS Hotels/ Remote nodes	•Flexibility in the choice of site, independent of radio aspects
Low power and small size of the Node devices	•Minimum environmental and electromagnetic impact •Ease of installation and maintenance
Low power consumption of the system	•Minimization of running costs •High reliability
Flexibility in number of nodes in the rings	•Ease with which coverage can be extended
Bandwidth of the fibre optic transmitting infrastructure	•Open architecture with regards other services (e.g. civic data networks)

Table 3 - General Aspects