Simultaneous Dual Band Transmission Over Multimode Fiber-Fed Indoor Wireless Network

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ABSTRACT
Performance measurements of different combinations of digital enhanced cordless telecommunications packet radio service, global system for mobile communications, universal mobile telecommunication service, and 802.11g (54 Mbps) signals in a dual band configuration transmitted over an indoor wireless network fed by a low-cost 850-nm vertical-cavity surface-emitting laser (VCSEL)-300 m multimode fiber link are presented. The feasibility of such a system is demonstrated with error vector magnitude measurements which are within the required specifications.

Index Terms—Multimode fiber, radio over fiber, subcarrier modulation, wireless networks.

I. INTRODUCTION

Distributed antenna systems (DAS) can improve coverage and capacity inside buildings such as airports, train stations, shopping malls and corporate office premises [1]. The DAS transports radio carriers from a central unit (CU) to a number of remote antenna units (AUs). While fiber optic transmission systems offer a number of performance advantages, the use of multimode fiber (MMF) in DAS is extremely attractive as it is already installed in many large buildings and continues to be installed in greater quantities than single-mode fiber due to its ease of handling [2]. Typical lengths of pre-installed MMF are up to 300 m [2]. The MMF modal dispersion limitation to the bandwidth is affected not only by fiber length but also by laser type and launch condition [3]. At frequencies beyond the fiber's 3-dB bandwidth, the MMF response is relatively flat. This can be used for communications via subcarrier modulation techniques, with a variety of lasers at different wavelengths [3]–[7], although troughs in the response do occur.

Simultaneous transmission of multiple signals over in-building DAS would be particularly attractive, for example to neutral host providers, providing shared infrastructure costs for different operators and service providers. Simultaneous dual band transmission of 802.11a and 802.11g wireless local area network (WLAN) signals over a MMF-fed indoor wireless network with an uncooled 1300 nm distributed feedback (DFB) laser has been demonstrated in [7]. This involved both optical and wireless path transmission, although details of the wireless link are not specified. Simultaneous transmission of four different wireless systems has been demonstrated in [8], where the wireless systems were paired, each pair modulating a separate electro-absorption modulator; the two optical signals were coupled together and transported over single-mode fiber. Good signal performance for all four wireless systems was reported. For short wavelengths and MMF, transmission of WLAN signals at 2.4 GHz and 5 GHz using vertical-cavity surface-emitting lasers (VCSELs) was demonstrated in [9] with good signal performances reported. Individual transmission of global system for mobile communications (GSM) and wideband code division multiple access (WCDMA) signals over a VCSEL-MMF link was demonstrated in [10]. However, the experiments conducted in [8]–[10] were without wireless paths. The inclusion of the wireless path is important in any demonstrator as it generally causes the greatest impact due to multipath signal fading (confirmed as significant in our laboratory with omni-directional antennas), while the optical path and optical-electrical conversion units restrict radio signal power.

In this letter, the transmission of different combinations of digital enhanced cordless telecommunications (DECT) packet radio service (DPRS), GSM, universal mobile telecommunication service (UMTS), and 802.11g (54 Mbps) signals in dual band configuration over an 850-nm operation wavelength MMF-fed indoor wireless network is demonstrated. Low-cost, commercially available VCSELs, photodiodes, and MMF with a length of 300 m were used for the optical link. Inexpensive, omnidirectional multiband antennas were used in the wireless path.We confine ourselves to a demonstration of system performance; full predictions of range based on our analyses require more complete explanation and are presented in [11].

II. EXPERIMENTAL SETUP

The measurements were conducted in a 10 m 10 m room. While line-of-sight between AU and mobile equipment was maintained, multipath effects were evident due to laboratory clutter.

A. Downlink

Fig. 1 shows the downlink setup of the MMF-fed wireless transmission experiments. The CU transmitter has two independent signal sources, each capable of emulating GSM, UMTS, DPRS, and WLAN systems. The system properties, used in the emulation, were taken from the respective standards documents [12]–[15] and are shown in Table I. The powers from the two signal sources were not optimized, but set to equal levels, 2 dBm in this case, which was the maximum available for the OFDM signals. Taking into account cable/combiner losses, this corresponded to a total drive power to the VCSEL of approximately -2.5 dBm. Measurements for the other systems showed that only for signals approximately 7-dB higher than this was a marked increase in error vector magnitude (EVM) due to laser nonlinearity observed. Thus, significant improvement over the link performances reported here could be expected. The combined signals were used to modulate the drive current of an ULM-Photonics multimode VCSEL (maximum output power 3 mW). The VCSEL, packaged in an SMA receptacle for fiber connection, has an aperture size of 20 µm with an annular farfield emission pattern [16]. It can be presumed that this corresponds to a restricted modal launch condition in which a majority of the higher order modes of the fiber are excited. The modulated optical signal was then transported to the AU through a 300-m length of Corning SXi 50 µm-core MMF (this fiber has specifications somewhat superior to OM2 MMF). The AU was mounted on the ceiling in the center of the room. At the AU, an Appointech photodiode (PD) was followed by amplifiers (Mini Circuits ZX-2510M) with 24-dB total gain. An omnidirectional multiband planar antenna [17] emitted the signal wirelessly to the mobile receiver (MR). The MR consisted of an omnidirectional perpendicular antenna, 160-dB gain amplifier (ZX-2510M) and EVM measuring equipment (Agilent E8408A VXI mainframe connected to laptop with Agilent VSA software).

TABLE I
PROPERTIES OF WIRELESS SYSTEMS EMULATED

Systems	Freq. (GHz)	Modulation	Data Rates	Filter Type	Max rms EVM
GSM	1.8	GMSK	270.833 ksym/s	Gaussian BT=0.3	7.0 %
DPRS	1.88	64 QAM	1.152 Msysm/s	RRC $\alpha = 0.5$	2.6 %
UMTS	2.0	QPSK	3.84 Msysm/s	RRC $\alpha = 0.22$	12.5 %
IEEE 802.11g	2.412	64 QAM - OFDM	54 Mbps	Gaussian BT=0.5	5.6 %

B. Uplink

In the uplink setup, the two signal sources and RF combiner previously implemented in the downlink CU were used with the omnidirectional perpendicular antenna as the mobile transmitter (MT). The AU consisted of the planar antenna [17], 24-dB amplification and the VCSEL. The modulated optical signal is transmitted through the same MMF used for the downlink to the CU, which consisted of the PD followed by 16-dB amplification and the

EVM measuring equipment (see Fig. 2).

III. MEASUREMENT RESULTS

A. Downlink

The signal power and rms EVM averaged over 100 measurements for each system in dual band configurations were recorded at the input of the AU antenna, and are shown in Table II. Each rms EVM measurement uses 1000 symbols. The rms EVM measured at the MR was not stable due mainly to multipath effects in the wireless channel. Thus, six sets of 100 rms EVM readings with an interval of 10 s between each set were recorded. The mean rms EVM and its standard deviation (σ) were calculated from all 600 rms EVM readings. Table III shows these computed rms EVM measurements at the MR for signal transmission over both optical and wireless links, either at the maximum wireless range for which the received signal conformed to the standard's requirements, or at the maximum physical distance possible in the room (5 m). The standard deviation values signify the stability of the measurements, and the reliability of the rms EVM values quoted. In all experiments no equalization was used at the receiver equipment.

TABLE II
DOWNLINK—AVERAGE rms EVM AT INPUT OF AU ANTENNA

Systems	Measured Signal	Antenna Unit	
		Inband Power	rms EVM
DPRS and IEEE 802.11g	DPRS	-3.5 dBm	1 %
	IEEE 802.11g	-4.9 dBm	2.5 %
GSM and IEEE 802.11g	GSM	-2.5 dBm	2.7 %
	IEEE 802.11g	-4.9 dBm	1.9 %
UMTS and IEEE 802.11g	UMTS 2.0GHz	-5.0 dBm	1.8 %
	IEEE 802.11g	-5.0 dBm	1.8 %
UMTS and GSM	UMTS 2.0GHz	-4.1 dBm	0.9 %
	GSM	-3.4 dBm	2.4 %
UMTS 2.0 GHz and UMTS 2.01GHz	UMTS 2.0GHz	-3.2 dBm	0.9 %
	UMTS 2.01GHz	-3.4 dBm	1.1 %

B. Uplink

Table IV shows the signal power and rms EVM of the UMTS and IEEE 802.11g systems when simultaneously transmitted from the MT. The transmitted signal powers (-4.3 dBm) were relatively low with respect to the maximum transmit power of typical mobile equipment (17–20 dBm). This was to ensure that the transmitted signals did not interfere with commercial radio systems outside the experimental room. Table V shows the rms EVM measurements at the CU (computed in a similar manner to those of Table III) for the signal transmission over both the wireless and optical links.

TABLE III
DOWNLINK—AVERAGE rms EVM AT THE MOBILE RECEIVER

Systems	Measured Signal	Mobile Receiver		
		Mean rms EVM	σ	AU-MR Distance
DPRS and IEEE 802.11g	DPRS	2.0 %	0.2	1.0 m
	IEEE 802.11g	3.8 %	0.3	4.2 m
GSM and IEEE 802.11g	GSM	4.6 %	0.6	5.0 m
	IEEE 802.11g	4.4 %	0.5	3.2 m
UMTS and IEEE 802.11g	UMTS	10.4 %	1.4	5.0 m
	IEEE 802.11g	4.0 %	0.9	3.5 m
UMTS and GSM	UMTS	9.3 %	1.2	3.8 m
	GSM	3.7 %	0.9	5.0 m
UMTS 2.0 GHz and UMTS 2.01GHz	UMTS 2.0GHz	10.6 %	0.3	2.4 m
	UMTS 2.01GHz	11.6 %	0.5	2.8 m

TABLE IV
UPLINK—AVERAGE rms EVM AT THE MOBILE TRANSMITTER

Systems	Measured Signal	Antenna Transmitter	
		Inband Power	rms EVM
UMTS and IEEE 802.11g	UMTS 2.0GHz	-3.4 dBm	0.9 %
	IEEE 802.11g	-4.3 dBm	1.8 %

TABLE V
UPLINK—AVERAGE rms EVM AT THE CENTRAL UNIT

Systems	Measured Signal	Central Unit		
		Mean rms EVM	σ	MT-AU Distance
UMTS and IEEE 802.11g	UMTS 2.0GHz	8.8 %	2.6	4.25 m
	IEEE 802.11g	4.7 %	0.5	1.2 m

C. Discussion

The results in Tables III and V show that a received signal of EVM within the maximum allowed for each system could be received. Although, for some systems, only small distances—this is the distance at table-top level from a position directly below the AU—were achievable, it should be noted that the system experiments did not involve optimization for radio range. So, whereas equal powers were always used for both systems, allowance could be made for the system with the more demanding requirements. Higher downlink powers could have been used, as stated in Section II-A, and uplink MT powers were deliberately limited as stated in Section III-B. There are further considerations for real systems [11]. There will be interference from the downlink signal being coupled back to the uplink; this can be reduced by filtering in frequency division duplex (FDD) systems and switched amplifiers/echo suppression for time division duplex (TDD) systems, but would require a very complex AU for a multiband system. Then, spurious emissions of each transmitting system in the receive bands of other systems need to be within limits specified in the standards; for simultaneous transmission of TDD and FDD signals, it would have to be assumed that the TDD signal is always present as an interfering signal.

IV. CONCLUSION

It has been shown that different combinations of DPRS, GSM, UMTS, and 802.11g (54 Mbps) signals in a dual band configuration can be transmitted over an indoor wireless network fed by a low-cost 850-nm VCSEL-MMF optical link with EVM measurements within the required specifications.

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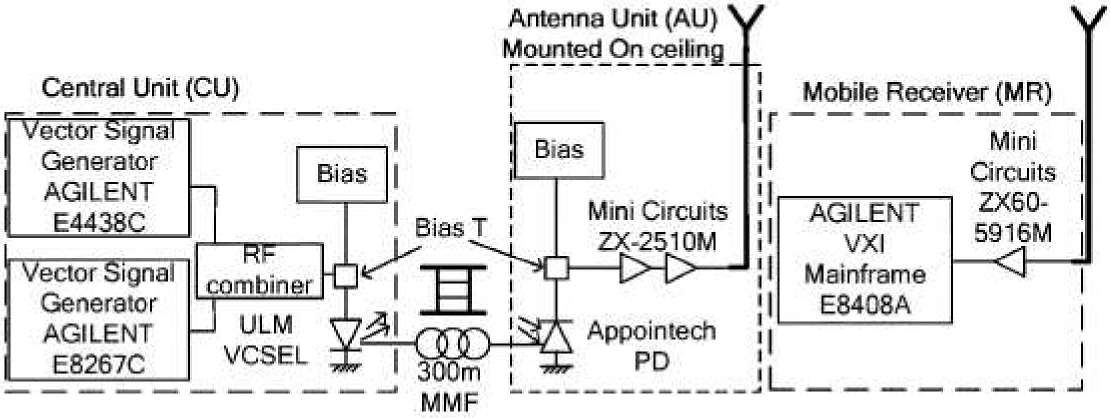

Fig. 1. Downlink experimental setup used for the simultaneous dual band radio transmission over 50 μm MMF with a length of 300 m.

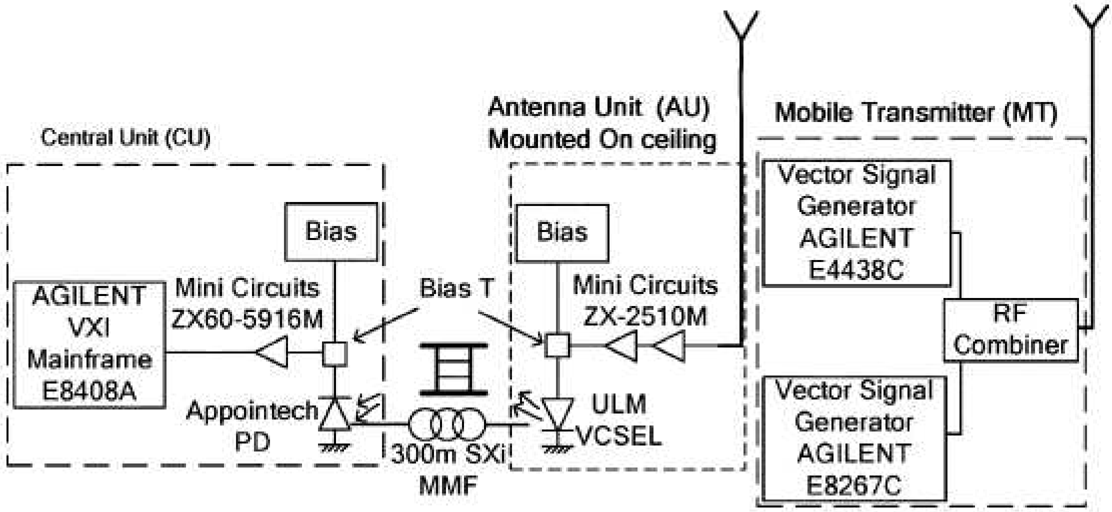

Fig. 2. Uplink experimental setup used for the simultaneous dual band radio transmission over 50-μm MMF with a length of 300 m.