Asynchronous Multi-Service Fiber-Wireless Integrated Network Using UFMC and PS for Flexible 5G Applications

You-Wei Chen, Rui Zhang, Shang-Jen Su, Shuyi Shen, Qi Zhou, Shuang Yao and Gee-Kung Chang

[1]*School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30308, USA*

**yu-wei.chen@ece.gatech.edu*

Abstract: A multi-service fiber-wireless integrated network is experimentally demonstrated using both UFMC and PS. Asynchronous transmission with suppressed inter-service interference and optimized information rate is verified through a 25-km fiber and a 5-m 60-GHz wireless link.

OCIS codes: (060.2330) Fiber optics communications; (060.4080) Modulation.

1. Introduction

The next-generation radio access [1] is envisioned to be a user-centric network for supporting extremely diverse applications, e.g., 8K video, mobile data, virtual reality/augmented reality (VR/AR) wearables and industrial internet of thing (I-IoT). Therefore, a multi-service network is required, and it is an important enabler for making 5G a reality, as shown in Fig. 1(a). Intuitively, multicarrier signal format, i.e., orthogonal frequency division multiplexing (OFDM) is one of the mainstreams for 5G applications, and each demanding signal in different applications should be optimized in its frame structure with different numerologies according to their service requirements. However, as the multi-service signal composed by the conventional OFDM format co-exists in a fiber-wireless integrated network, it would result in a high out-of-band emission and cause severe inter-service interference, especially in the case of massive service transmitted asynchronously and arranged spectrally side-by-side with an insignificant guard band among them. In this case, the service in the center of the spectrum would suffer from most inter-service interference, as shown in Fig. 1(b).

To improve the frequency localization of each service and reduce the inter-service interference, filter bank multicarrier (FBMC) [2] and universal filtered multicarrier (UFMC) [3,4] were proposed. Considering that UFMC can be implemented via the fast Fourier transform (FFT) based digital signal processing (DSP) as OFDM and it adopts subband filter, for mitigating the sidelobe leakage which reduces the required filter length as compared to FBMC. Therefore, UFMC is more suitable for 5G applications. The multi-service signal could be generated with dedicated subband filter and assembled in the central unit (CU) or distributed unit (DU) before launched into the mobile fronthaul. At the user equipment (UE) side, each service signal could be decoupled via the paired subband filters. On the other hand, to fully utilize the channel in certain achievable signal-to-noise ratio (SNR), probabilistic shaping (PS) [5] technology was widely studied in the optical communication field. In contrast to the conventional QAM scheme, which has non-continuous SNR state for uniform distributed QAM level, PS could achieve a continuous information rate tuning via modifying the probability of each constellation point. Therefore, by finely adjusting the information rate (i.e., entropy), PS can fully utilize the channel SNR. However, in the OFDM multi-service scheme, each service suffers from different amount of out-of-band interference. It implies different PS setting must be implemented and dynamically modified according to its frequency allocation, which significantly increases the system complexity and reduces the network flexibility.

In this paper, we experimentally demonstrated a novel flexible fiber-wireless integrated network with mitigated multi-service interference. In comparing to the OFDM scenario, less guard band is required, and asynchronously transmitted multi-service signals exhibit more uniform performance in the UFMC scheme. In case of system signal transmission cannot meet the 3GPP 64QAM requirement after 25-km fiber transmission and over 5-m 60-GHz wireless channel, it must fall back to 32QAM in a uniform QAM scheme. By applying UFMC and PS, a common entropy setting could be applied and the available information rate meeting the 3GPP threshold is 5.97 bits/symbol, which sacrifices only 0.5% data rate, to enable an enhanced mobile broadband in a flexible multi-service network.

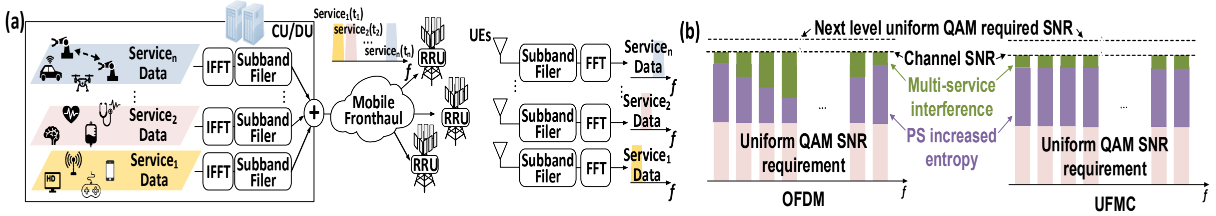

Fig. 1 (a) Conceptual diagram of a multi-service fiber-wireless convergence with UFMC. (b) Conceptual diagram of the multi-service interference variation in OFDM and UFMC schemes with PS increased entropy in a massive-connection multi-service network.

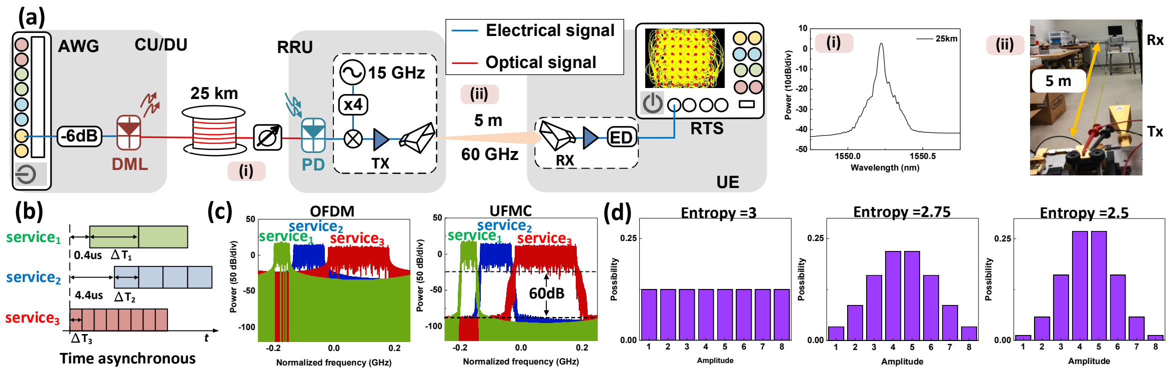

Fig. 2 (a) Experimental setup of multi-service fiber-wireless integrated network with asynchronous transmission. (b) Time delay of different services with different numerologies. (c) Electrical spectra for three services in OFDM and UFMC schemes. (d) One-dimension PS distribution with different entropy (i) Optical spectrum after 25-km fiber transmission. (ii) Photograph of wireless transmission setup.

2. Operation principles and experimental setup

Figure 2(a) shows the experimental setup of the proposed multi-service mobile fronthaul. Without loss of generality, three services based on multicarrier format with different numerologies are generated via offline DSP. The FFT size for Service#1, #2 and #3 are 4096, 2048 and 1024 with 408 active subcarrier number, and thus they occupy 50, 100, and 200 MHz bandwidth, respectively. All service signals are 64-QAM modulated and sampled with a 500 MSa/s rate. The OFDM and UFMC signal are generated via ordinary DSP, including serial (parallel)-to-parallel (serial) conversion, (inverse) FFT, and subband filtering [4,6]. For UFMC generation, 12 subcarriers are assigned in each subband and Chebyshev filter with 60-dB sidelobe attenuation ratio is adopted to reduce the out-of-band leakage to nearby signals. To mimic asynchronous transmission among service operator, 0.4, 4.4 and 0 us time delay are embedded in front of the three signal frames, as shown in Fig. 2(b). The spectra of multi-service OFDM and UFMC with 14.6-MHz guard band are exhibited in Fig. 2(c). One can note that a relatively high out-of-band emission can be observed in the OFDM scheme, which is around 60 dB higher than what is shown in the UFMC scheme. The two-dimensional PS-64QAM is generated via combing two amplitude shaping signal, which is formed by the conventional constant composition distribution matching (CCDM) [5] with the Maxwell-Boltzmann distribution. The possibility of each power level in the amplitude shaping signal is adjusted according to the target information rate, i.e., entropy. As shown in Fig. 2 (d), starting with uniform distribution, the transmission rate and variance are gradually reduced to better fit in the channel SNR condition. Before, digital-to-analog conversion via an arbitrary waveform generator (AWG), multi-service signal is firstly offline upconverted to 300MHz central frequency to concurrently conduct the complex signal generation and circumvent the block frequency around DC [6]. A 6-dB power attenuator is applied at the output of AWG to prevent overdriving the subsequent 10-GHz direct-modulated distributed feedback laser (DML), which is operated at 1550.2 nm and 4.6 dBm output power. At RRU side, an optical attenuator is employed after 25-km fiber transmission for manipulating the received power testing. The corresponding optical spectrum after 25-km transmission is inset in Fig. 2(i). After optical-to-electrical conversion via a 5-GHz bandwidth photodetector (PD), the received multi-service signal is then up-converted and transmitted over-the-air via a wireless transmitter set, including a 12.5-GHz sinusoidal source generator, a 4-times frequency multiplier, a mixer, a 25-dB gain power amplifier and a V-band antenna with 25-dBi gain. The wireless transmission distance is 5 m in this demonstration, which implies an 81.98-dB propagation loss. To compensate the loss, at the UE side, a 20-dBi gain horn antenna and a 35-dB gain low noise amplifier are applied before the employed envelope detector (ED). The received signal is sampled, and analog-to-digital converted via a real-time scope (RTS) with 20 GSa/s rate. In the decoding DSP, one-tap zero-forcing (ZF) equalizer is applied for compensating the channel impairments in both OFDM and UFMC scenarios and we evaluate the received performance via the error vector magnitude (EVM).

3. Experimental results

Figure 3(a) exhibits the EVM performance of both OFDM and UFMC in back-to-back (btb) scheme with -1 dBm received optical power and over 5-m wireless transmission versus the launched amplitude for DML. In the lower driven amplitude region, the received power is limited by lower SNR; while with the higher launched amplitude, the multicarrier signal would suffer from the nonlinear modulation of DML. The optimal performance for both signal formats is at around 250 mV, which imply they have a similar peak-to-average power ratio. However, due to higher out-of-band interference, the received performance of OFDM is slightly degraded. Figure 3(b) and (c) show that the EVM performance as a function of the received optical power for OFDM and UFMC in btb and after 25-km fiber

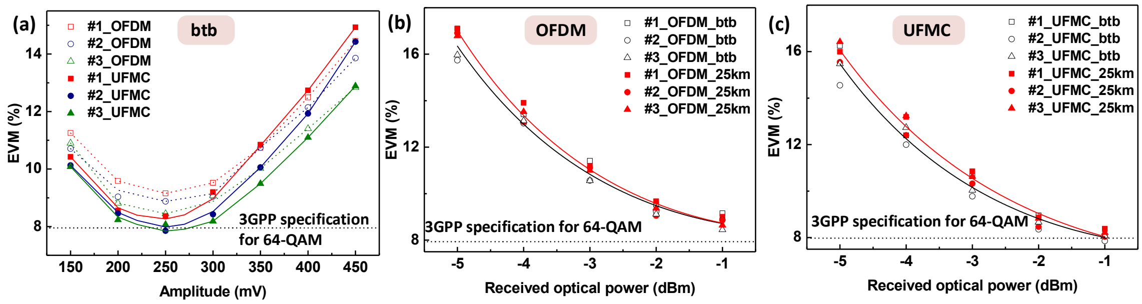

Fig. 3 (a) The multi-service EVM performance in OFDM and UFMC schemes versus input amplitude of DML in btb and after 5-m wireless transmission. (b) and (c) the received EVM performance various received optical power in btb and after 25-km transmission with 14.6 MHz guard band between each service.

transmission. Due to the multicarrier scheme, the inter-symbol interference is not significant, and thus there is a negligible power penalty between btb and after 25-km fiber transmission. One can note that only the maximum received power of -1 dBm in the UFMC scheme can reach the 3GPP requirement for 64-QAM after 25-km fiber transmission, which implies the multi-service signals must downgrade to 32-QAM with information rate reduction from 6 bit/s to 5 bit/s in a uniform QAM scenario.

Figure 4(a) displays the EVM performance varies with the guard band spacing between each service. The EVM performance is degraded significantly in OFDM scheme for Service#1 and #2, which could be understood since Service#2 allocated in the middle, and thus suffers more out-of-band interference. Although Service#1 is allocated in the lowest frequency, it has the closest subcarrier spacing and the narrowest signal bandwidth, and therefore it is still sensitive to the interference from the neighboring services. On the other hand, Service#3 stays at the highest frequency and has larger subcarrier spacing and bandwidth, it has more tolerance to out-of-band interference. In the UFMC scenario, less guard band is required since the subband filter provides a higher sidelobe attenuation and tolerable EVM degradations of 0.2%, 0.59% and 0.33% for Service#1, #2 and #3, respectively, are measured. To fully utilize the channel condition, PS-64QAM is applied to balance the achievable data rate and the received signal performance as shown in Fig. 4 (b) and (c). We use signal variance to qualify system performance, which is defined as $\mathrm{Var}(\mathrm{Sig}_{\mathrm{Tx}} - \mathrm{Sig}_{\mathrm{Rx}})$, where both the transmitted signal and received signal are scaled to the same level of amplitude. For OFDM Service#1, #2 and #3, the achievable entropies under the specified signal variance for 8% EVM requirement of uniform 64QAM are 5.73, 5.9, and 5.71 bits/symbol. OFDM scheme requires different PS setting or it can sacrifice the information rate to 5 bit/s for multi-service network with the same received sensibility. In the UFMC scenario, as we reduce the possibility of the outer points of 64QAM constellation, the received variance for all service is quite stable and monotonously reduced. The available data rate under the threshold for UFMC multi-service signal is 5.97 bits/symbol, which is 19.7% enhanced compared with uniform 32QAM.

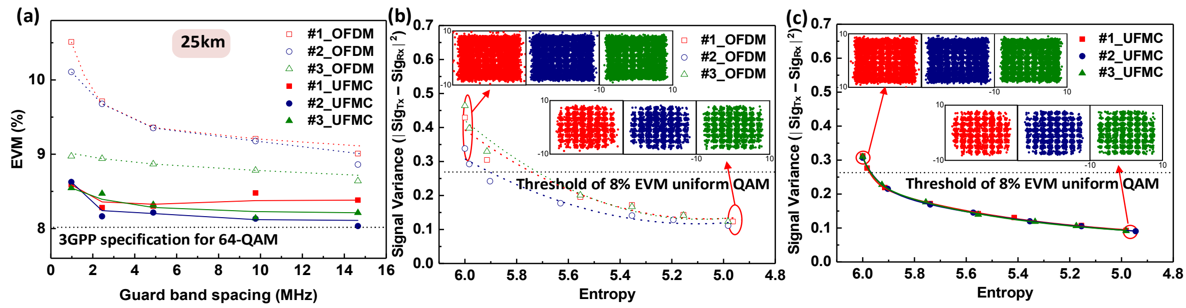

Fig. 4 (a) EVM measured over 5-m 60GHz wireless channel and after 25-km transmission in different guard band spacing between each service. (b) and (c) the received signal variance performance various entropy after 25-km transmission with 1 MHz guard band between each service.

4. Conclusions

A novel multi-service network using UFMC and PS is experimentally demonstrated for mitigating the out-of-band interference and fully utilizing the channel SNR over 5-m wireless channel and 25-km fiber transmission. 5.97 bits/symbol transmitted information rate is achieved with common PS setting for multi-service with different numerologies and asynchronous transmission, which enables a flexible 5G network for diverse service applications.

5. References

[1] G. K. Chang, et al. in *Proc. OECC*, paper S1-2 (invited) (2018).
[2] B. Farhang-Boroujeny, Signal Process. Mag. **28**, pp. 92 (2011).
[3] F. Schaich, et al., in *Proc. ISCCSP*, pp. 457-460 (2014).
[4] H. Cho, et al., in *Proc. WCNC*, pp. 1-5 (2017).
[5] P. Schulte, et al., Trans. Inform. Theory. 62, pp. 430 (2016).
[6] Y.-W. Chen et al., J. Lightwave Technol. **37**, pp. 3236 (2019).