# SINR-Oriented Flexible Quantization Bits for Optical-Wireless Deep Converged eCPRI

Longsheng Li*, Meihua Bi*†, Wei Wang*, Yan Fu*, Xin Miao* and Weisheng Hu*
*State Key Laboratory of Advanced Optical Communication Systems and Networks, Shanghai Jiao Tong University, Shanghai, China, email: wshu@sjtu.edu.cn
† School of Communication Engineering, Hangzhou Dianzi University, Hangzhou, China, email: bmhua@hdu.edu.cn

***Abstract*—The split-PHY and Ethernet-based eCPRI is mostly advanced for reducing fronthaul line rate and leveraging Ethernet protocol. In this paper, a fundamental method is proposed to compress the eCPRI data by dynamically adjusting the quantization bits of IQ sample according to the corresponding wireless signal quality of user equipment. With the aid of this mechanism, the fronthaul traffic is correlated to the eventual end-user traffic instead of the air bandwidth, and hence the flexibility and the bandwidth efficiency of the interface can be further improved. To verify this proposal, a simulation model achieving the complete low-MAC layer and PHY layer processing for LTE uplink and strictly following the 3GPP specifications is built. The results indicate that for the typical mobile environment, the proposed scheme can statistically save ~20% interface bandwidth.**

***Keywords*—eCPRI, split-PHY, SINR, quantization bit, flexibility**

## I. Introduction

Fueled by the low-cost broadband services and the high-level coordination technologies, the centralization of baseband units (BBU) becomes the mainstream [1,2] for the 5G access network. To support this architecture, the exploration of novel interface for mobile fronthaul (MFH) is critical to efficiently deliver the radio signal data among BBUs and remote radio heads (RRHs). As one of the major standardized interfaces, the common public radio interface (CPRI) [3] transmits the continuous time-domain in-phase and quadrature signal (IQ) samples with fixed 30 quantization bits, therefore it would consume large bandwidth and limits the flexibility and feasibility of MFH. To solve this problem, the split-PHY architecture combined with Ethernet networking has been widely investigated [4],[5]. And the standardized eCPRI [6] has also been proposed to reduce the MFH traffic and leverage the mature packet transport standard. In eCPRI, the function split point for uplink is implemented after the resource element demapping. Base on this split, the interface bandwidth is significantly reduced and the MFH traffic volume can scale flexibly according to the number of physical resource blocks (RBs), or the used air bandwidth. This feature highly promotes the bandwidth efficiency and benefits the statistical multiplexing, whereas, the eventual MFH efficiency, or the fronthaul to backhaul bandwidth ratio [7], is still significantly limited by the quality of wireless channel. Since in a practical mobile communication system, a certain number of RBs is assigned to each user equipment (UE) for its transmission. And according to the number of RBs and the channel quality of the UE, a specific modulation and coding scheme (MCS) is chosen to modulate the data of end-users, namely the transport block (TB), onto the RBs. In this situation, for the uplink transmission, owing to the transmission of wireless Rayleigh fading channel, the signal qualities of UEs' RBs vary dramatically, and the end-user data rate supported by different UEs' RBs also strongly fluctuate [8]. Therefore, if all RBs is uniformly packaged in MFH interface regardless of its real data capacity, the eventual MFH efficiency for a specific UE is highly determined by its wireless signal quality, or correspondingly its MCS. As shown in Fig. 1, with 6 physical RBs and 10-bit quantization for IQ sample, the ratio of MFH line rate contributed by IQ sample to the end-user data rate decreases with the MCS index [9] (the high-order MCS is applied to high-quality signals). This result indicates that the eventual MFH efficiency for the RBs filled with low-quality signal is inefficient. Fortunately, in eCPRI specification, the quantization bit width and format for RB samples, or the frequency-domain IQ samples, are vendor specific [6], which offers a desirable interface to intelligently package the data of IQ sample. Moreover, as presented in [14], the frequency-domain IQ signals with diverse signal quality are not equally sensitive to the quantization resolution, among which the signal with a low signal to interference and noise ratio (SINR) has a large margin for quantization resolution and hence demands fewer quantization bits. Consequently, based on the SINR monitoring, the redundant bits for the quantization of low-quality signal should be located and saved in eCPRI.

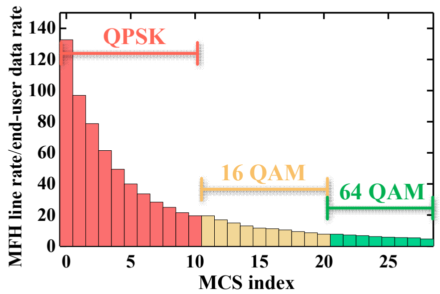


Fig. 1. Bandwidth efficiency of MCS. MCS: modulation and coding scheme.

In this paper, for the first time, we propose and demonstrate a flexible quantization bits (FQB) scheme for uplink eCPRI, which leverages the monitoring of signal quality in wireless system to lower the MFH traffic. The potential redundant quantization bits are predicted in our scheme, where the RRH is informed of the signal quality by the BBU through real-time control information on user plane, based on which the optimal

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quantization bits are configured for every uplink LTE subframe. With this mechanism, the redundant bits for low-quality RBs are reduced, and hence the eventual MFH traffic. The results of the simulation system with the configuration specified in [9,13] convince that about 17~23% traffic can be saved by the FQB.

The rest of the paper is organized as follows. Section II introduces the relevant background of the mobile communication system. Section III describes the architecture of the proposed MFH link and explains its feasibility. Section IV shows the simulation results comparing the FQB scheme with the ordinary uniform quantization bits (UQB) scheme, and Section V concludes this paper.

## II. BACKGROUND AND MOTIVATION

### A. *Influence of split-PHY architecture on MFH interface*

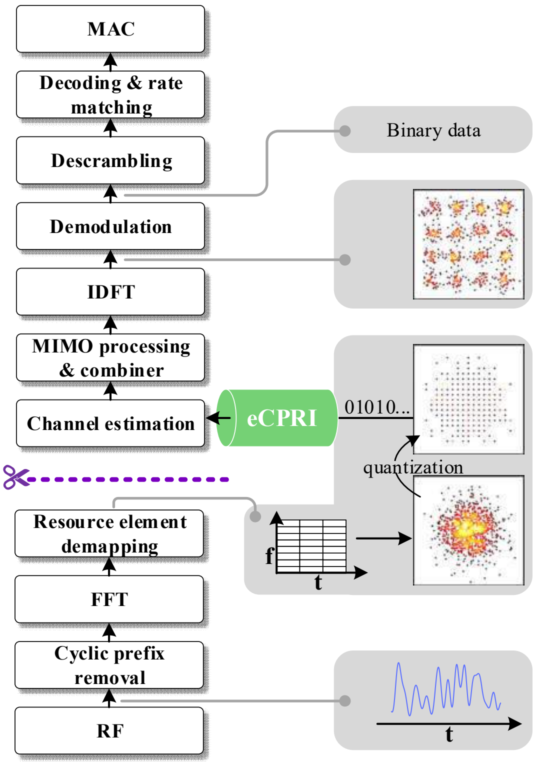


Fig. 2. LTE function layers and signal format at each interface.

Figure 2 is the schematic of LTE function layers with signal formats attached. As illustrated in this figure, the user plane data of eCPRI is the frequency-domain IQ sample from the resource element demapping, which should be quantized before packaged into the eCPRI frame. Obviously, more quantization bits bring less quantization noise at the cost of losing bandwidth efficiency. Different from the time-domain quantization [15] in CPRI, the quantization noise in eCPRI does not spread over the entire physical uplink frequency band, instead, it only takes effect among the corresponding frequency-domain IQs which are then together used for the demodulation of a specific UE. In other words, the frequency division multiplexed UEs can be served by independent quantization resolution.

### B. *Fidelity of frequency-domain quantization*

Due to the transmission of frequency selective Rayleigh fading channel, the qualities of received frequency-domain signals are diverse. In the model given in 3GPP specification [9] section A.2.2, for typical uplink scenarios, the variance among the SINR of UEs is more than 10 dB. These signals with different SINR also have different sensitivities to the quantization resolution. Figure 3 shows the relationship between the SINR of quantized signal and that of the unquantized signal. To give this result, the simulation model following 3GPP standard as described in section III is used. It can be seen that the deterioration caused by quantization is significant for the high-quality signal, in comparison, the low-quality signal is much less sensitive to quantization noise, hence its fidelity can be satisfied by relatively fewer quantization bits. Based on this feature, the major idea of our proposal is to detect the SINR of UE's RBs, and according to which the optimal quantization bits are configured to prevent redundancy bits.

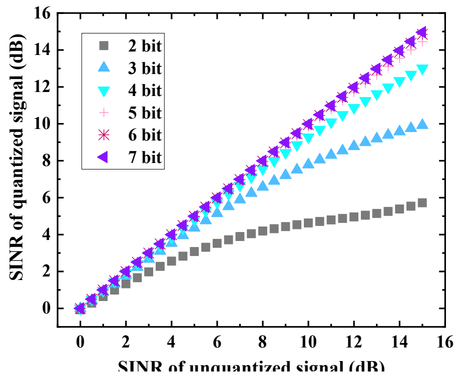


Fig. 3. SINR of quantized and unquantized signal.

## III. ARCHITECTURE AND SIMULATION MODEL OF ECPRI WITH THE FQD

### A. *System architecture based on eCPRI*

Figure 4 illustrates how the SINR monitoring and quantization bit control fit into to the eCPRI-based MFH interface to achieve the SINR-oriented FQB, note that the referential eCPRI protocol stack can be found in [6] section 3 and the interfaces for the C&M and the synchronization plane are irrelevant to THE FQD, thus not presented here. The eCPRI user data plane contains three types of information: user data (the IQ sample), real-time control data and other eCPRI services. The FQB for uplink works as follows. At the RRH, the IQ samples are firstly quantized by the initial quantization bits. Then, together with other information, the user data are transmitted through MFH link with eCPRI. At the BBU, the received IQ samples are used for low-PHY demodulation, where the SINR is also measured. This SINR is passed to a quantization bit manager which adjusts the number of quantization bits by looking up a preset table. The quantization bit control command is added to the real-time control information and passed back to the RRH. And afterward, the RRH read this command and adjust the quantization bits for the forthcoming samples. Note that the overhead for quantization bit control is negligible since one SINR measuring presents the signal quality of one subframe consisting of a large number of IQ samples from one UE. Besides, this FQB control has a delay approximate to the one-way delay of eCPRI. Fortunately, this shall be low enough to follow the change of wireless channel. For comparison, the delay of adaptive modulation and coding (AMC) in LTE is no less than 7 subframe cycles [13], namely ~7 ms.

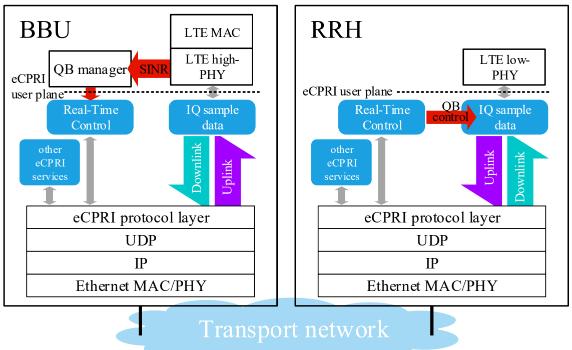


Fig. 4. System architecture of eCPRI with the SINR-oriented FQB. QB: quantization bit.

### B. Simulation model

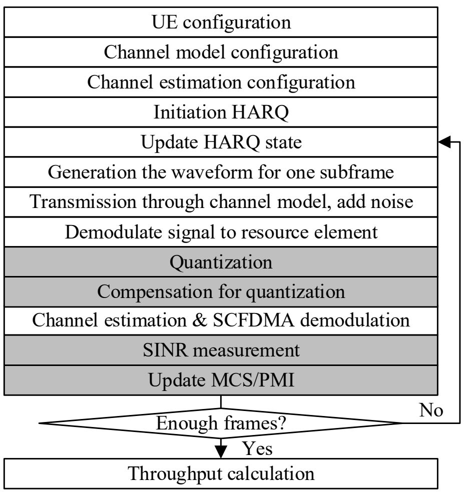


Fig. 5. Working flow for uplink simulation with adaptive modulation and coding.

To verify the feasibility of the proposal, we build a simulation system achieving the entire PHY-layer processing and Low-MAC layer processing ending at HARQ. The simulation platform is Matlab, and all functions, unless otherwise specified, are based on Matlab standardized LTE System Toolbox [16]. The major objects of the simulation are to a) determine the optimal FQB strategy, b) compare the bandwidth efficiency between the FQB scheme and the UQB scheme, and c) find the FQB's influence on final end-user throughput. Note that although the simulation is based on LTE air interface, this proposal also works for the forthcoming 5G situation, since the SINR diversity will always exist.

Figure 5 presents the processing flow of the simulation, in which the grey function modules are additionally added or customized compared to the standard system. For the quantization processing, all IQ samples within one subframe are quantized by the same number of bits. The resolution of quantization bit in this system is 0.1, and non-integer bit is achieved by quantizing a portion of the samples with the bit number rounded toward negative infinity, and the rest with the bit number rounded toward positive infinity. The compensation for quantization is done by filling the lost lowest bits with random binary bits. In realistic LTE link, the AMC is employed, which lets UE with high-quality adopt high-order MCS to realize better spectral efficiency. Nevertheless, in 3GPP specification, the strategy of selecting appropriate MCS according to channel quality is not given and should be vendor specific. Based on this situation, we employ a maximum throughput strategy for AMC. For a given SINR, the concept of this strategy is simply to choose the MCS that can achieve the maximum throughput with cyclic redundancy check (CRC) success ratio considered. Hence, in section 0, the throughput versus SINR for all 29 MCSs [12] is measured to produce an SINR-MCS table for AMC. In AMC processing, the updated quantization bits together with the updated MCS take effect after 7-subframe delay as defined in [13]. The major parameters of the simulation are listed in TABLE I.

TABLE I
PRIMARY PARAMETERS OF THE SIMULATION

| Parameter | Quantity |
|---|---|
| SRS[a] periodicity | 2 ms |
| Delay of MCS update | 7 ms |
| Transmitter antenna number | 2[b] |
| Receiver antenna number | 1[b] |
| Channel Delay profile model | EPA-5[c] |
| Rayleigh fading model type | GMEDS[d] |
| Transmission bandwidth | 90 KHz (6 RBs) |
| Frame number | 500 |
| Average SNR | 5 dB |

[a]Sounding reference signal.
[b][13].
[c]Extended Pedestrian A model with 5-Hz Doppler frequency.
[d]Generalized Method of Exact Doppler Spread.

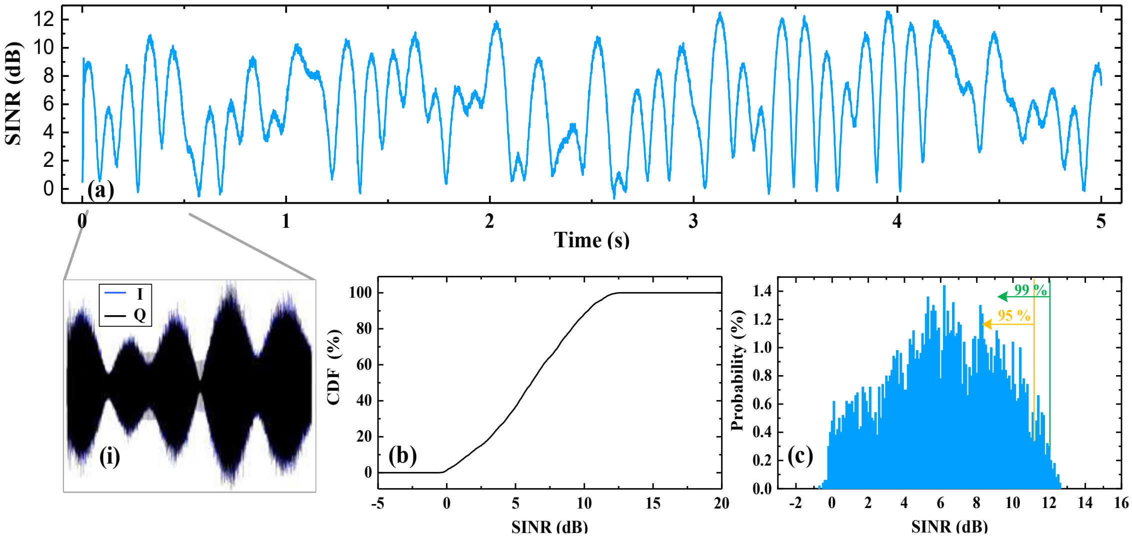


Fig. 6. (a) SINR variation during 5 ms, (b) the cumulative distribution and (c) probability distribution of SINR.

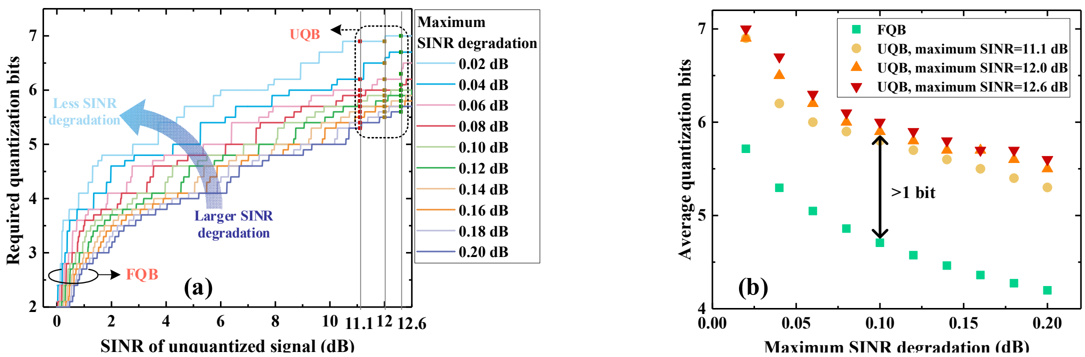


Fig. 7. (a) minimum quantization bits satisfying SINR degradation threshold versus SINR of the unquantized signal in the FQB and UQB scheme, (b) statistical average quantization bits versus SINR degradation threshold. The threshold here is set for maximum SINR deterioration.

## IV. SIMULATION RESULT

### *A. Reduction of quantization bits*

To make the result convincing and significant enough, the SINR distribution of the wireless signal in our model is firstly simulated which is utilized for further statistical measurement. Figure 6(a) presents the SINR variation over 5 seconds, namely 500 frames, and the inset (i) gives the corresponding time-domain IQ waveform during the first 0.5 second. Based on this result, the probability distribution and the cumulative distribution of SINR are further shown in Fig. 6(b) and (c). The CDF of SINR obtained here is approximate to the reference model given in 3GPP specification [13] Section A.2.2.

Then, the relationship between the SINR of unquantized signal and that of quantized signal is tested, which is achieved by bypassing the transmission channel module and only attaching the additive noise. Therefore, the noise power can be easily controlled and any possible unquantized SINR can be covered. The fitting results for the integer quantization bits situations are presented in Fig. 3. In this paper, the signal fidelity of MFH interface is depicted by the maximum tolerable SINR degradation induced by quantization process. With the SINR relationship between unquantized and quantized signal, the minimum quantization bits satisfying the threshold of SINR deterioration can be determined at each unquantized signal SINR, and the SINR to bit number mapping table is built for the FQB. As shown in Fig. 7(a), the curves of the FQB scheme are non-decreasing functions, where the low-SINR signal demands relatively fewer bits. In general, stricter tolerance of SINR degradation is supported by more quantization bits. As for the UQB scheme, the tolerable SINR degradation should be satisfied at the maximum unquantized SINR. Based on the result of SINR distribution, three typical values, 12.6, 12.0 and 11.1 dB are treated as the maximum unquantized SINR in turn, which can cover 100%, 99% and 95% of the SINR distribution respectively. The corresponding required bits for the three values in the UQB are circled in Fig. 7(a).

With the SINR distribution obtained and the quantization strategies determined, the statistical average quantization bits for MFH interface can be measured. The results are given in Fig. 7(b), which exemplify that the FQB scheme can noticeably reduce the quantization bit by ~1 bit for any SINR degradation requirement compared to the UQB scheme. Typically, with Maximum SINR degradation being 0.1 dB, the FQB scheme can save 20.2% quantization bits compared to the UQB scheme with the maximum SINR set as 12.0 dB.

## B. End-user throughput

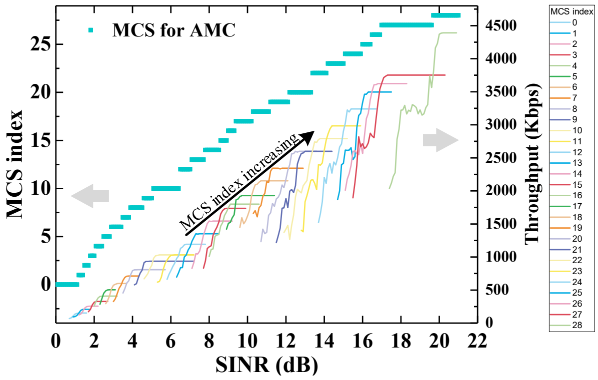


Fig. 8. Throughput versus SINR with fixed MCS index and chose MCS index versus SINR in AMC.

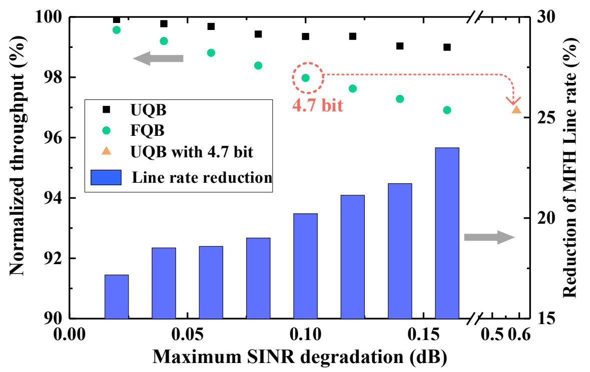


Fig. 9. Working flow for uplink simulation with adaptive modulation and coding.

The proposed FQB scheme and the UQB scheme are applied to the uplink system including the channel transmission and the AMC to benchmark their influence on the final end-user throughput. Firstly, to determine the working range of each MCS for AMC, the throughput versus SINR for each MCS is individually tested. The measured throughput and the chosen MCS index at corresponding SINR are exhibited in Fig. 8. Based on this uplink system, the throughput for the FQB scheme and the UQB scheme with maximum unquantized SINR set as 12.0 dB are compared, and the result is depicted in Fig. 9. Here, the throughput is normalized by dividing the throughput of the unquantized system. It is revealed that the throughput for the FQB is decreased by only 1% while the MFH line rate is saved by 17~23% compared to the UQB counterpart. Therefore, it is convinced that the FQB is able to compress the eCPRI interface traffic without significantly sacrificing the end-user throughput. For reference, the UQB with 4.7 quantization bits, which are the statistical average bits of FQB scheme at 0.1 dB SINR degradation, is tested. Compared to its FQB counterpart, the UQB scheme with 4.7 bit has ~1% lower throughput and ~0.58 dB worse maximum SINR degradation. It can be seen from this result that compared to directly decreasing quantization bits, the FQB can cause less injury to the wireless signal.

# V. CONCLUSION

In this paper, we propose a novel MFH quantization scheme which exploits the existing function in the wireless system to assist the transmission of split-PHY-based MFH. The number of quantization bits for the MFH interface is flexible according to the signal quality of the frequency-domain samples, thus the redundant bits are significantly decreased. Following the 3GPP specification, the simulation results reveal that ~20% uplink MFH can be compressed, and compared to traditional uniform quantization scheme, the end-user throughput is barely sacrificed in the FQB scheme. Therefore, the proposed scheme could be an effective solution to improve the MFH efficiency.

# ACKNOWLEDGEMENT

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