Digitized radio over TDM-PON system with bandwidth reduction technique using wireless resource allocation

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\textbf{Abstract:} We propose a novel data bandwidth reduction method based on wireless resource allocation for digitized radio over a TDM-PON system. The proposed method reduces the sampling frequency of each BBU-RRU link with minimal degradation in wireless signal quality and the provision of a statistical multiplexing gain. Simulations show that the required PON bandwidth is reduced by 30\% when there are 68 mobile terminals.

\textbf{Keywords:} distributed antenna system, digitized RoF, TDM-PON

\textbf{Classification:} Wireless Communication Technologies

\textbf{References}

1 Introduction

In cellular systems such as long-term evolution (LTE) and worldwide interoperability for microwave access (WiMAX), the flexible deployment of base stations is achieved by apportioning their functions between a baseband unit (BBU) and a remote radio unit (RRU) [1]. BBU provides the baseband processing functions, while RRU provides the radio transmission and reception functions. BBU and RRU are separate and connected by optical links. Wireless signals between BBU and RRU are transmitted by employing radio over fiber (RoF) technologies. There are two types of RoF: analog RoF and digitized RoF (DRoF). In DRoF, digitized baseband or low-IF wireless signals are transmitted via fiber, and RRU control and management signals are multiplexed into them as in the common public radio interface (CPRI) technique [2]. DRoF imposes negligible degradation on the wireless signals in optical transmission.

Distributed antenna systems are easily configured with DRoF technologies, and the C-RAN architecture proposes that RRUs in multiple cells are connected to collocated BBUs for centralized control and coordinated operation [3]. In this architecture, wireless signals received by RRUs are collected at BBUs for joint reception established among RRUs, and joint transmission among RRUs is also performed by centralized BBU processing, so that cell-edge user throughput is improved. To realize high-performance wireless access, a large number of RRUs are linked to collocated BBUs, so a cost-effective wired network solution is essential.

The most promising candidate for these links is the time division multiplexing passive optical network (TDM-PON). It provides cost-effective connectivity since an optical fiber is shared by multiple RRUs (hereafter this configuration is referred to as digitized radio over TDM-PON system). TDM-PON has about 10 Gbps capacity as in IEEE802.3av. DRoF requires a very large and fixed data bandwidth in proportion to the sampling frequency and the number of quantization bits [2]. Therefore, it is necessary to reduce the required data bandwidth.

In this paper, we propose a new method to further reduce the required data bandwidth for digitized radio over TDM-PON [4]. The proposed method reduces the sampling frequency according to the used wireless bandwidth. Simulation results show that, when there are 64 mobile terminals, the required PON bandwidth is reduced by 30% with negligible degradation in wireless signal quality.

2 Proposed system

Fig. 1 shows the proposed digitized radio over TDM-PON system. BBU and RRUs of base stations are connected by a TDM-PON system. BBU and RRU implement optical line terminal (OLT) and optical network unit (ONU) functions of the PON, respectively. Wireless baseband signals are transmitted between the BBU and RRUs by employing DRoF technologies.

The total required bandwidth for up or down link, $R_{\text{total}}$, is calculated by
Fig. 1. Schematic of digitized radio over TDM-PON system, and spectrum at reference points when $f_{s,i}$ is $f_{s,orig}/2$.

\[
\sum_{i=1}^{N_{RRU}} f_{s,i} N_{quant} N_{ant}.
\]
where $N_{RRU}$ is the number of RRUs, $f_{s,i}$ is the sampling frequency for transmission between a BBU and RRU# $i$ ($i = 1, 2, \ldots, N_{RRU}$), $N_{\text{quant}}$ is the number of quantization bits of the in- and quadrature-phase parts, and $N_{\text{ant}}$ is the number of antennas. This calculation assumes that the same frequency channels are used by all antennas of a given RRU.

2.1 Wireless resource allocation

Orthogonal frequency division multiplexing (OFDM) is used in LTE and WiMAX. In OFDM systems, the system bandwidth is divided into multiple frequency channels consisting of $N_{\text{sub}}$ subcarriers. The base station performs wireless resource allocation with period of $T_{\text{cyc}}$ in order to assign frequency channels to mobile terminals (MTs). The number of channels assigned to each MT is decided so as to satisfy the MT’s request. Some frequency channels are not used when there are few MTs associated with an RRU and their required wireless bandwidth is small.

2.2 Bandwidth reduction method

The proposed method reduces the required data bandwidth of each BBU-RRU link by reducing the effective sampling frequency based on wireless resource allocation. The proposed method provides the TDM-PON system with statistical multiplexing gain since the required data bandwidth of each BBU-RRU link is dynamically reduced.

During downlink transmission, the modem of the BBU outputs digitized wireless signals with sampling frequency, $f_{s,\text{orig}}$. The compressor reduces $f_{s,\text{orig}}$ to $f_{s,\text{orig}}/n$ ($n = 1, 2, 3, \ldots$) by puncturing $n - 1$ in every $n$ samples (hereafter, $n$ is called the compression ratio). The compression ratio is decided based on the bandwidth of the wireless signal being used, $B_{\text{used}}$, such that the degradation in wireless signal quality is acceptable. $B_{\text{used}}$ is known from the wireless resource allocation information. The compressor can be composed of a decimation filter and a real-valued compression ratio can be realized by upsampling digitized wireless signals before reducing the sampling frequency. The framer converts digitized wireless baseband signals and wireless resource allocation information into frames of the PON.

In an RRU, the deframer extracts digitized wireless baseband signals and wireless resource allocation information from the PON frames. The decompressor changes $f_{s,\text{orig}}/n$ to $f_{s,\text{orig}}$ by inserting $n - 1$ null samples in each sample. The baseband filter suppresses the aliasing caused by up sampling. The RRU can know the compression ratio and the filter weight vector from the wireless resource allocation information, and these parameters can be dynamically changed in every $T_{\text{cyc}}$. For further elimination of redundant data, the BBU does not transmit data to the inactive RRU to which no MTs belong. The proposed method is also applied to the uplink by using wireless resource allocation information for uplink.
Table I. Simulation Parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>System bandwidth available for transmission</td>
<td>18 MHz</td>
</tr>
<tr>
<td>Bandwidth per frequency channel</td>
<td>180 kHz</td>
</tr>
<tr>
<td>The number of subcarriers per frequency channel ($N_{sub}$)</td>
<td>12</td>
</tr>
<tr>
<td>Scheduling cycle ($T_{cycle}$)</td>
<td>0.5 ms</td>
</tr>
<tr>
<td>Original Sampling frequency ($f_{offset}$)</td>
<td>30.72 MHz</td>
</tr>
<tr>
<td>The total number of quantization bits of in- and quadrature-phase ($N_{quant}$)</td>
<td>24 bits</td>
</tr>
<tr>
<td>Modulation scheme, Coding rate</td>
<td>QPSK, 1/2</td>
</tr>
<tr>
<td>The number of RRU's ($N_{RRU}$)</td>
<td>8</td>
</tr>
<tr>
<td>The number of antennas ($N_{ant}$)</td>
<td>2</td>
</tr>
<tr>
<td>Filter type</td>
<td>equi-ripple FIR</td>
</tr>
<tr>
<td>The number of filter taps</td>
<td>1000</td>
</tr>
<tr>
<td>Corner frequency of stopband</td>
<td>$30.72/n$ MHz</td>
</tr>
<tr>
<td>Transition bandwidth</td>
<td>90 kHz</td>
</tr>
<tr>
<td>Stopband attenuation</td>
<td>$&lt;50$ dB</td>
</tr>
<tr>
<td>Passband ripple</td>
<td>$&lt;0.02$ dB</td>
</tr>
</tbody>
</table>

3 Simulation Results

Simulations were conducted to evaluate the performance of the proposed method. Table I shows the simulation parameters. The wireless system parameters are derived from LTE PHY [5].

3.1 Compression ratio

The proposed compression method is irreversible and degrades the error vector magnitude (EVM) of wireless signals. The EVM caused by the proposal, $EVM_{com}$, is evaluated by comparing the wireless signals in Fig. 1 (a) and Fig. 1 (c). The allowable EVM, excluding proposal, $EVM_{prop}$, is calculated by the following equation.

$$EVM_{prop} \leq \sqrt{(EVM_{orig})^2 - (EVM_{com})^2} [%],$$  \hspace{1cm} (2)

where $EVM_{orig}$ is the allowable EVM for the wireless system.

Fig. 2 (a) shows the maximum compression ratio as a function of $B_{used}$, while satisfying $EVM_{com}$. $EVM_{orig}$ is set to 17.5% for QPSK modulation [6]. The maximum compression ratio increases as $B_{used}$ is reduced because the degradation effect of the aliasing noise on the wireless signal decreases. The maximum compression ratio increases as $EVM_{prop}$ is reduced. When $EVM_{com} = 1\%$, the proposed method reduces the sampling frequency with negligible degradation in wireless signal quality.

The maximum compression ratio for 64QAM is almost the same as that for QPSK because the aliasing noise power is independent of the modulation scheme. $EVM_{orig}$ for 64QAM is 8% [6] and, when $EVM_{com} = 1\%$, $EVM_{prop} = 7.93\%$. Therefore, the proposed method when $EVM_{com} = 1\%$ is effective with any modulation format.

3.2 Reduction of required data bandwidth

The data bandwidth reduction performance of the proposed method was evaluated. The number of MTs is $N_{MT}$ and each MT randomly belongs to one
of the RRUs. The wireless signal of each MT is assumed to be randomly distributed throughout the system bandwidth. The required bandwidth for transmitting the wireless resource allocation information is a few Mbps with these parameters and thus is negligible compared with that needed for transmitting the wireless signals.

Fig. 2(b) plots average $R_{\text{total,ave}}$ as a function of $N_{\text{MT}}$, assuming that EVM$_{\text{com}}$ is 1%. In the conventional method, $R_{\text{total,ave}}$ is fixed because the sampling frequency is fixed, so the conventional method cannot exploit the statistical multiplexing gain. The conventional method requires 1.47 Gbps for each BBU-RRU link, so more than 5 RRUs cannot be supported by the capacity of a 10G-EPON excluding PHY overhead, 8.7 Gbps [7].

It is shown that the proposed method reduces $R_{\text{total,ave}}$ compared with the conventional method by exploiting statistical multiplexing gain. The introduction of the proposed method has a large effect when the required transmission rate per MT, $R_{\text{MT}}$, is small and $N_{\text{MT}}$ is small. This is because $B_{\text{used}}$ is small and the compression ratio is large. Compared with the conventional method, the proposed method reduces $R_{\text{total,ave}}$ by 50% when $N_{\text{MT}} = 36$ and 30% when $N_{\text{MT}} = 68$. The proposed method allows 10G-EPON to provide the required data bandwidth when simultaneously transmitting to up to 76 MTs. The maximum number of simultaneously transmitting MTs is
reduced to realize a margin for dealing with the variation in of $R_{\text{total}}$, and high $R_{\text{MT}}$. However, the use of 16QAM and 64QAM for wireless signal modulation results in reducing the required bandwidth of the wireless signals and increasing the number of simultaneously transmitting MTs.

4 Conclusion

In this paper, we proposed a method that reduces the required data bandwidth for digitized radio over TDM-PON system based on wireless resource allocation. Simulation results show that the proposed method significantly reduces the required data bandwidth in a PON. The proposed method can be applied to other types of TDM-based PONs such as the large-capacity wavelength division multiplexing (WDM)/TDM-PON for the enlargement of the number of sectors and frequency bands in cellular systems [8].