Ultra-Mini Slot Transmission for 5G NR URLLC Systems

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Abstract

Ultra-reliable and low-latency communication (URLLC) is a new service category to accommodate emerging services requiring low end-to-end latency. In the 4G LTE/5G NR, it is very difficult to satisfy the URLLC requirements since multiple OFDM symbols are processed as a bundle. In this paper, we propose a novel low-latency packet transmission scheme, referred to as ultra-mini slot transmission (UMST), suitable for the short packet transmission in URLLC scenario.

I. INTRODUCTION

Ultra-reliable and low-latency communication (URLLC) is a new service category introduced in 5G to accommodate emerging services requiring low end-to-end latency called mission-critical applications [1]. To support this service, 3GPP sets a stringent requirement that a packet should be delivered with 10^{-5} packet error rate within 1 msec end-to-end latency [2]. In the current 4G LTE systems, it is very difficult to satisfy the URLLC requirements since multiple OFDM symbols are processed as a bundle. In order to decode the resource block in LTE system, a mobile device has to receive 7 OFDM symbols and it takes 0.5 msec just for the buffering samples. Hence, it is highly likely that the URLLC latency requirement cannot be satisfied with an ordinary receiver processing.

In this paper, we propose a ultra low-latency packet transmission scheme suitable for the short packet transmission in URLLC scenarios. The main idea of the proposed scheme, henceforth referred to as ultra-mini slot transmission (UMST), is to transform the short-sized information into a sparse OFDM symbol vector and then decode it using a small number of received time-domain samples. It is now well-known that as long as the sensing mechanism preserves the input information, the input sparse vector can be recovered with a small number of measurement [3]. By choosing early arrived samples, we can achieve a significant reduction of the receiver processing latency (i.e., latency of transmission, buffering, and decoding).

II. RECEIVER PROCESSING LATENCY

In this section, we briefly review the receiver processing latency $T_{Rx}$ in the downlink 4G LTE/5G NR systems. At the mobile device, the duration from the beginning of the sample transmission to the end of the decoding process can be expressed as the sum of three distinct latency components:

$$T_{Rx} = T_{prop} + T_{buff} + T_{dec}$$

where $T_{prop}$ is the propagation latency, $T_{buff}$ is the time to receive the transmitted signal, $T_{dec}$ is the time to decode the transmit information. Among these delay components, we primarily focus on the reduction of the buffering latency $T_{buff}$ since $T_{buff}$ is much larger than $T_{prop}$ and $T_{dec}$.

When delivering a packet in a form of RB in LTE system, a mobile device needs to receive 7 OFDM symbols. In this case, $T_{buff}$ equals to one slot period (i.e., 0.5 msec), which is too large to meet the URLLC latency requirement due to the time-consuming control signaling (e.g., 0.5 msec for the PDCCH transmission). In order to reduce $T_{buff}$, NR system supports the short transmission mode, called minislot transmission. In the minislot transmission, the mobile device needs to buffer the time-domain samples corresponding to 2 ~ 4 symbols to initiate the decoding process and the buffering time $T_{buff}$ is 0.15 ~ 0.3 msec.

One can deduce from this fact that when supporting the latency-critical applications (e.g., less than 0.1 msec for the smart factory), conventional transmission scheme is not a viable option. Therefore, an entirely new transmission scheme to achieve a significant reduction of $T_{buff}$ is required.

III. ULTRA-MINI SLOT TRANSMISSION

Fig. 1 depicts the overall description of the UMST scheme. The key operation of UMST is to transform the short-sized packet into a sparse vector. When encoding the transmit information into the sparse signal vector $\mathbf{s}$, a small number of subcarriers (say $k$ out of $N$) are chosen. Distinctive feature of UMST over the conventional transmission scheme is that positions as well as symbols can be employed to convey the information.

After the UMST encoding process, the IFFT is applied. Then, the time-domain sample vector $\mathbf{s}_t$ is transmitted through the channel. The relationship between the transmit
sparse vector $\mathbf{s}$ and the received time-domain sample vector $\mathbf{y}$ can be expressed as

$$\mathbf{y} = \mathbf{H}\mathbf{s} + \mathbf{n} = \mathbf{H}\mathbf{F}\mathbf{s} + \mathbf{n}$$

where $\mathbf{H}$ is the channel matrix, $\mathbf{F}$ is the IFFT matrix, and $\mathbf{n}$ is the noise vector. After removing the cyclic prefix, $\mathbf{H}$ can be decomposed by the DFT matrix $\mathbf{F}^H$ (i.e., $\mathbf{H} = \mathbf{F}\mathbf{F}^H$ where $\mathbf{\Sigma}$ is the diagonal matrix whose element is the frequency-domain channel coefficient for each subcarrier). Thus, we have

$$\mathbf{y} = \mathbf{F}\mathbf{\Sigma}\mathbf{s} + \mathbf{n} = \mathbf{F}\mathbf{x} + \mathbf{n}$$

where $\mathbf{x} = \mathbf{\Sigma}\mathbf{s}$ is the composite vector.

Based on the theory of CS, as long as the sensing mechanism preserves the energy of an input sparse vector, $k$-sparse vector can be recovered with a small number of measurements $m = c\log N$ ($c$ is a constant) [3]. In our system model, $\mathbf{x}$ and $\mathbf{F}$ correspond to the sparse vector and the sensing matrix so that $\mathbf{x}$ can be recovered from a part of $\mathbf{y}$. This means that a small portion of firstly arrived samples in $\mathbf{y}$ is enough to decode the transmit information. The corresponding measurement vector $\tilde{\mathbf{y}}$ is

$$\tilde{\mathbf{y}} = \Pi\mathbf{y} = \Pi\mathbf{F}\mathbf{x} + \tilde{\mathbf{n}} = \mathbf{A}\mathbf{x} + \tilde{\mathbf{n}}$$

where $\Pi$ is the selection matrix to pick the first $m$ samples, $\tilde{\mathbf{n}} = \Pi\mathbf{n}$, and $\mathbf{A} = \Pi\mathbf{F}$ is the partial IDFT matrix.

Since the information is conveyed by both subcarrier positions (support) and symbols, two operations (i.e., support identification and symbol detection) are needed for the decoding of the UMST packet. First, to find out the nonzero positions of $\mathbf{s}$, we need to identify the support of $\mathbf{x}$, which is done by the sparse signal recovery algorithm [3]. After identifying the support, rest of information can be decoded by detecting the symbol vector.

The advantages of UMST can be summarized as follows. First and foremost, the decoding process is done with a small number of time-domain samples. When compared to the RB-based and minislot-based transmission, $T_{\text{buff}}$ of the UMST scheme can be reduced substantially (more accurately, $T_{\text{buff}}$ is less than one symbol period). Second, the transmit power can be saved considerably. Noting that the required number of samples in the receiver is small, the BS does not need to transmit whole samples, resulting in a significant reduction of the transmit.

**V. CONCLUSION**

In this paper, we proposed a novel low-latency transmission scheme suitable for the short packet transmission in URLLC scenarios. We demonstrated from the numerical evaluations that the proposed UMST scheme is very effective in terms of both the reliability and latency.

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**REFERENCE**

