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Invited Papers

Fronthaul evolution: From CPRI to Ethernet

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ABSTRACT

It is proposed that using Ethernet in the fronthaul, between base station baseband unit (BBU) pools and remote radio heads (RRHs), can bring a number of advantages, from use of lower-cost equipment, shared use of infrastructure with fixed access networks, to obtaining statistical multiplexing and optimised performance through probe-based monitoring and software-defined networking. However, a number of challenges exist: ultra-high-bit-rate requirements from the transport of increased bandwidth radio streams for multiple antennas in future mobile networks, and low latency and jitter to meet delay requirements and the demands of joint processing. A new fronthaul functional division is proposed which can alleviate the most demanding bit-rate requirements by transport of baseband signals instead of sampled radio waveforms, and enable statistical multiplexing gains. Delay and synchronisation issues remain to be solved.

1. Introduction

1.1. Background

Next-generation (5th generation, 5G) mobile networks are faced with providing a step-change in capability due to the explosion of mobile device usage and the ever-increasing capabilities of the end-user devices. The requirements for 5G are also manifold, as it is envisaged that it will cater for high-bandwidth high-definition streaming and conferencing, to machine interconnectivity and data collection for the Internet of Things, including ultra-low latency applications such as driverless cars.

The higher wireless user data-rates envisaged in next-generation mobile networks (up to 10 Gb/s in proposals for 5G systems [1]) generally demand the use of shorter radio transmission distances. These shorter distances in cellular mobile communications can be achieved through smaller cells (each with its own small base station) [2] or by distributing the antenna heads, usually termed remote radio heads (RRHs) into each cell [3], see Fig. 1. The latter approach is seen to provide certain advantages [4]: (1) it can lead to a greater degree of centralization, with pools of base station baseband units (BBUs) connected to large numbers of RRHs, this enabling flexibility in the connections to meet varying traffic demands in the coverage area, a reduced demand in the need for base station sites, and improved energy efficiency due to the sharing of the power requirements of the co-located base stations; (2) improved coverage in the cell; (3) virtualisation and "cloudification" of base station functions in cloud-radio access networks (C-RANs); (4) enhanced possibilities for joint processing of signals transmitted from and received by different RRHs, such as the enablement of co-ordinated multipoint (CoMP), through low-latency interconnection of the co-located BBUs.

There are challenges, however, in providing the *fronthaul* distribution links between BBUs and RRHs, and these will increase for next-generation mobile networks [5]. The principal challenge lies in the increased bandwidth/bit-rate. The information transported between BBUs and RRHs is generally in the form of sampled radio signals. Already, for long-term evolution-advanced (LTE-A) signals which may have bandwidths up to 100 MHz, a single uncompressed sampled radio waveform requires a link bit-rate of over 5 Gb/s (assuming 16-bit samples). Up to now, compression factors of 2 have been shown to be lossless with some tolerable loss for a compression factor of 3 [6]. The bit-rate requirements for the much higher aggregate bandwidths expected in 5G can be expected to increase by more than an order of magnitude – of the order of tens of Gb/s. Further, this represents the bit-rate requirements of one radio stream, whereas RRHs will typically have a number of physical antenna elements requiring different radio signals.

The second significant challenge for the BBU-RRH design is the more exacting demands being placed on latency and jitter in current proposals for 5G [1]. Requirements for minimum latency

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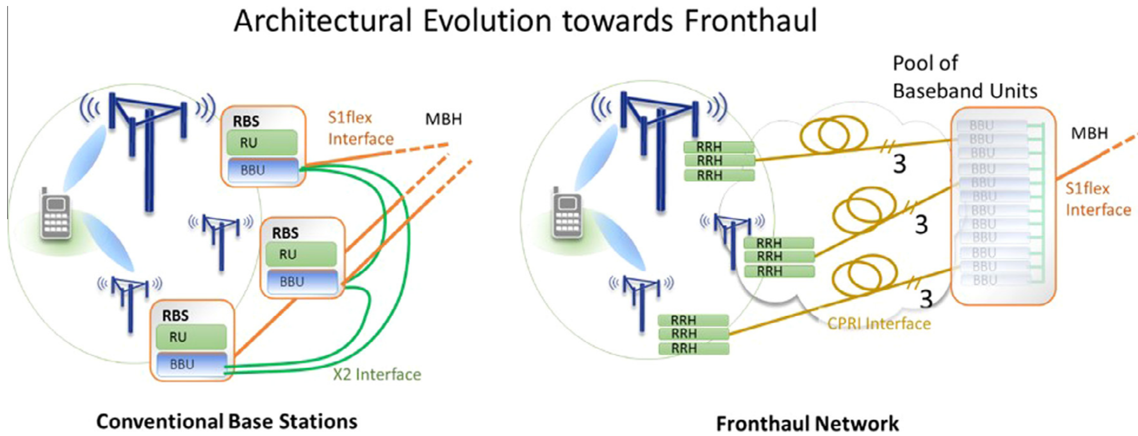

Fig. 1. Conventional, separate base stations and C-RAN with BBUs hosted, X2 channels connected locally and a fronthaul network connecting BBUs with RRHs (over CPRI links).

may come from user applications or from the needs of maintaining the relevance of channel state information; such latency definitions will not be restricted simply to the fronthaul, so the contribution of the fronthaul and the various components of delay within it may not be clearly defined. Compression, advantageous for reducing bit-rate requirements, may add to latency. Jitter may manifest itself in variations in the transmission times of the radio signals, effectively increasing the phase noise of the transmitted signals.

In order to make best use of the potential flexibility of the BBU-RRH fronthaul, an open and accommodating topology is required. This also provides a challenge. The most widely used current transport standard, the Common Public Radio Interface (CPRI) [7], indicated in Fig. 1, was originally defined as an internal base station interface to allow antenna functions to be moved to rooftops and mastheads, away from the baseband processing in the cabinet – the demand now is to use it over links of several km. If existing fibre network infrastructure is to be used, compatibility with Ethernet based technology is required. Although wavelength division multiplexing (WDM) overlays are possible, much of the mobile radio access network hardware is being built specifically for purpose.

Thus, current fronthaul standards such as CPRI, OBSAI (Open Base Station Architecture Initiative) [8] and ORI (Open Radio Interface) [9] provide dedicated transport protocols, specifically designed for and suited to the requirements of sampled radio waveform transport. The framing carried out, for example, is done at regular intervals with frame sizes matched to specific slices of the wireless system frames (the fronthaul transport frame length in bits expands with increasing bandwidth). This form of framing enables precise synchronisation of the RRH. However, as waveforms are transported, the bit rates are proportional to radio channel bandwidths and numbers of antenna elements (not, necessarily, user data rates). Further, the *continuous* transport of time-domain radio waveform samples leads to the absence of any possible statistical multiplexing gains as these signals are distributed over a fronthaul network. For operators, there are also questions about how to manage and provide service level agreements around the fronthaul service.

2. Ethernet in fronthaul

The use of Ethernet for transport in the fronthaul is appealing as a result of the maturity of the technology and its adoption within access networks. The operations, administration and maintenance (OAM) capabilities of Ethernet [10] offer a standardised means of managing, fault finding and supporting performance monitoring of the network.

It is possible to transport Ethernet in the fronthaul over CPRI, with Ethernet used to provide OAM functions missing in CPRI. The Ethernet "control channel" could be used to support network management protocols. The Ethernet signals are extracted from the CPRI/ORI equipment, which can retain their synchronisation mechanisms. However, apart from the use of OAM mechanisms, most of the advantages possible with the move to an open fronthaul transport protocol are not realised when using CPRI as the underlying transport layer. The use of Ethernet as the underlying transport layer may bring the following:

- Use of commodity equipment, or at least lower-cost, industry-standard equipment.
- Sharing of equipment with fixed access networks, enabling greater convergence and cost reductions.
- Use of switches/routers to enable statistical multiplexing gains and lower the aggregate bit-rate requirements of some links.
- Use of standard IP/Ethernet network switching/routing functionality, including moves to functional virtualisation and overall network orchestration.
- Monitoring through compatible hardware probes.

Thus, Ethernet could be used to transport CPRI/ORI frames. This would have the advantage of some backwards compatibility with existing equipment, with CPRI-Ethernet "mappers" and "de-mappers" at the edges of a fronthaul distribution system still allowing legacy equipment to transfer CPRI signals. However, it does lead to an additional framing overhead. An alternative, then, would be to place the radio waveform samples directly in Ethernet frames. The concern, in both cases, is the possible loss of the frame synchronism that is inherent in CPRI-type transport once placement in Ethernet frames is used. In Synchronous Ethernet, see Fig. 2, nodes extract the reference clock from received data rather than each node using its own internal oscillator. This mode of operation can certainly be helpful in telecoms networks, and standardisation has been led by ITU-T [11–13]. However, while frequency synchronism between devices in the network can be gained, additional mechanisms are required for precise time and phase synchronism. IEEE 1588, or Precision Time Protocol (PTP), is significant in this context, achieving synchronism through the exchange of time-stamped packets [14]. ITU-T, IEEE and others are continuing to develop standards for the use of both Synchronous Ethernet and PTP, individually or in combination, in various applications [15].