LTE-Advanced | Relay Technology | Self-backhauling

Technology Reports

Special Articles on LTE-Advanced Technology
—Ongoing Evolution of LTE toward IMT-Advanced—

Relay Technology in LTE-Advanced

The standardization of LTE-Advanced is now underway with the goal of achieving a next-generation high-speed and high-capacity mobile communications system. For LTE-Advanced, studies are being made on relay technology for achieving self-backhauling of the radio signal between the base station and mobile station on the layer 3 level. This technology aims to improve the received signal to inter-cell interference plus noise power ratio and enhance throughput. In this way, radio waves can be propagated more efficiently, coverage extended and throughput improved at cell edge.

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1. Introduction

Standardization activities are underway at the 3GPP, an international standardization organization, on LTE-Advanced with the aim of achieving high-speed, high-capacity communications beyond LTE, the standard for Third-Generation (3G) mobile communications systems. In LTE-Advanced, an important issue in addition to achieving high-speed, high-capacity communications is greater throughput for cell-edge users, and one means now being studied to accomplish this is relay technology for relaying radio transmissions between a base station and mobile station. Relays are expected to extend coverage in an efficient manner in various types of locations such as places where fixed-line backhaul links[*1] are difficult to deploy.

In this article, we describe deployment scenarios applicable to relay technology and the radio access technology, radio control technology, and architecture for achieving the relay technology now being standardized in 3GPP.

2. Overview of Radio Relay Technology

2.1 Types of Radio Relay Technologies

Radio-relay stations for relaying radio signals come in various types according to the relay technology adopted. Three types of radio relay technologies and their respective advantages and disadvantages are shown in **Figure 1**. A layer 1 relay consists of relay technology called a booster or repeater[*2]. This is an Amplifier and Forward (AF) type of relay

*1 **Fixed-line backhaul link**: Communication circuit for fixed-line interconnecting of equipment making up the mobile communications system such as switching stations and radio base stations.

*2 **Repeater**: Physical layer relay equipment that amplifies downlink signals received from a base station for transmission to a mobile station.

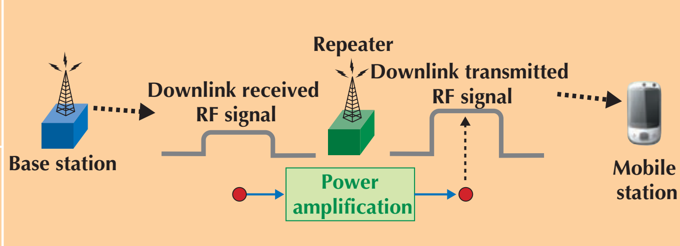
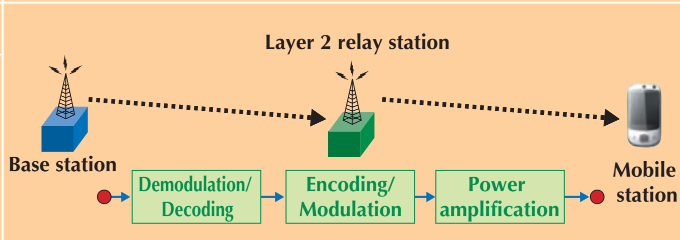
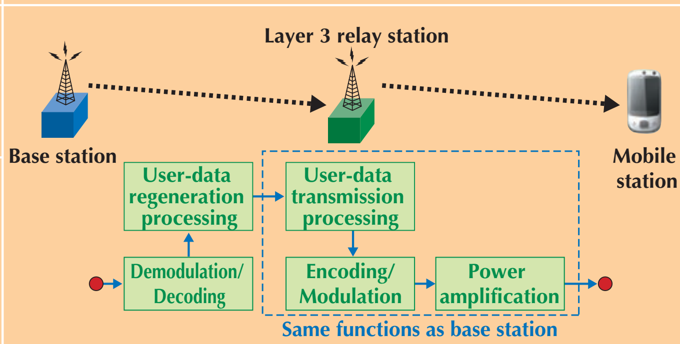
Radio relay technology	Advantages/Disadvantages		Overview
Layer 1 relay	Plus	・Simple and inexpensive functions ・Minimal impact on standard specifications (specifications on repeater performance already defined in LTE Rel. 8)	
	Minus	・Noise is amplified simultaneously with desired signals	
Layer 2 relay	Plus	・Elimination of noise	
	Minus	・Processing delay due to modulation/demodulation and encoding/decoding ・Radio control functions must be added between base station and relay station	
Layer 3 relay	Plus	・Elimination of noise ・Small impact on standard specifications	
	Minus	・Processing delay due to modulation/demodulation and encoding/decoding ・Layer 3 processing delay (user-data regeneration processing, etc.)	

Figure 1 Features of various radio relay technologies

technology by which Radio Frequency (RF) signals received on the downlink from the base station are amplified and transmitted to the mobile station. In a similar manner, RF signals received on the uplink from the mobile station are amplified and transmitted to the base station. The equipment functions of a layer 1 relay are relatively simple, which makes for low-cost implementation and short processing delays associated with relaying. With these features, the layer 1 relay has already found widespread use in 2G and 3G mobile communication systems. It is being deployed with the aim of improving coverage in mountainous regions, sparsely populated areas and urban areas as well as in indoor environments. The RF performance specifications for repeaters have already been specified in LTE, and deployment of these repeaters for the same purpose is expected. The layer 1 relay, however, amplifies inter-cell interference and noise together with desired signal components thereby deteriorating the received Signal to Interference plus Noise power Ratio (SINR) and reducing the throughput-enhancement gain.

The layer 2 relay, meanwhile, is a Decode and Forward (DF) type of relay technology by which RF signals received on the downlink from the base station are demodulated and decoded and then encoded and modulated again before being sent on to the mobile station. This demodulation and decoding processing performed at the radio relay station overcomes the drawback in layer 1 relays of deteriorated received SINR caused by amplification of inter-cell interference and noise. A better throughput-enhancement effect can therefore be expected compared with the layer 1 relay. At the same time, the layer 2 relay causes a delay associated with modulation/demodulation and encoding/decoding processing. In this type of relay, moreover, radio functions other than modulation/demodulation and encoding/decoding (such as mobility control[*3], retransmission control by Automatic Repeat request (ARQ), and user-data concatenation/segmentation/reassembly) are performed between the base station and mobile station transparently with respect to the radio relay, which means that new radio-control functions for supporting this relay technology are needed.

2.2 Layer 3 Relay Technology

The layer 3 relay also performs demodulation and decoding of RF signals received on the downlink from the base station, but then goes on to perform processing (such as ciphering and user-data concatenation/segmentation/reassembly) for retransmitting user data on a radio interface and finally performs encoding/modulation and transmission to the mobile station. Similar to the layer 2 relay, the layer 3 relay can improve throughput by eliminating inter-cell interference and noise, and additionally, by incorporating the same functions as a base station, it can have small impact on the standard specifications for radio relay technology and on implementation. Its drawback, however, is the delay caused by user-data processing in addition to the delay caused by modulation/demodulation and encoding/decoding processing.

In 3GPP, it has been agreed to standardize specifications for layer 3 relay technology in LTE Rel. 10 because of the above features of improved received SINR due to noise elimination, ease of coordinating standard specifications, and ease of implementing the technology. Standardization of this technology is now moving forward.

Layer 3 radio relay technology is shown in **Figure 2**. In addition to performing user-data regeneration processing and modulation/demodulation and encoding/ decoding processing as described above, the layer 3 relay station also features a unique Physical Cell ID (PCI) on the physical layer different than that of the base station. In this way, a mobile station can recognize that a cell provided by a relay station differs from a cell provided by a base station.

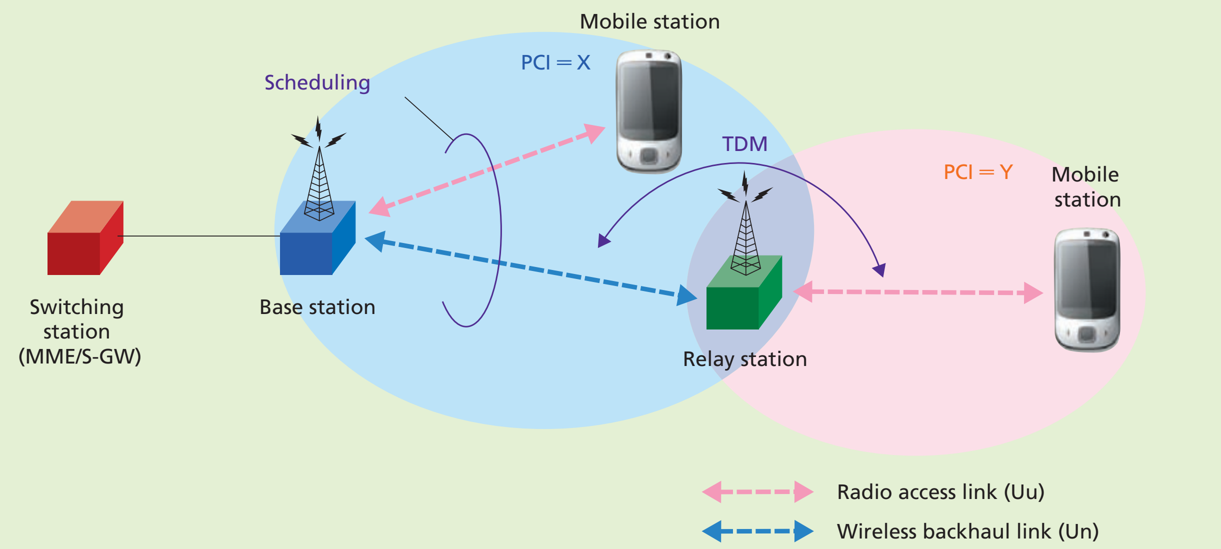


Figure 2 Overview of layer 3 relay technology

*3 **Mobility control**: A control function that enables the continuous provision of incoming and outgoing communications for moving terminals.

In addition, as physical layer control signals such as Channel Quality Indicator (CQI)[*4] and Hybrid ARQ (HARQ)[*5] can terminate at a relay station, a relay station is recognized as a base station from the viewpoint of a mobile station. It is therefore possible for a mobile station having only LTE functions (for example, a mobile station conforming to LTE Rel. 8 specifications) to connect to a relay station. Here, the wireless backhaul link (Un) between the base station and relay station and the radio access link (Uu) between the relay station and mobile station may operate on different frequencies or on the same frequency. In the latter case, if transmit and receive processing are performed simultaneously at the relay station, transmit signals will cause interference with the relay station's receiver by coupling[*6] as long as sufficient isolation[*7] is not provided between the transmit and receive circuits. Thus, when operating on the same frequency, the wireless-backhaul-link and radio-access-link radio resources should be subjected to Time Division Multiplexing (TDM)[*8] so that transmission and reception in the relay station are not performed simultaneously.

3. Deployment Scenarios for Relay Technology

Scenarios in which the introduction of relay technology is potentially useful have been discussed in 3GPP. Deployment scenarios are shown in **Table 1**. Extending the coverage area to mountainous and sparsely populated regions (rural area and wireless backhaul scenarios) is an important scenario to operators. It is expected that relay technology can be used to economically extend coverage to such areas as opposed to deploying fixed-line backhaul links. Relay technology should also be effective for providing temporary coverage when earthquakes or other disasters strike or when major events are being held (emergency or temporary coverage scenario), i.e., for situations in which the deployment of dedicated fixed-line backhaul links is difficult. In addition, while pico base stations and femtocells[*9] can be used for urban hot spot, dead spot, and indoor hot spot scenarios, the installation of utility poles, laying of cables inside buildings, etc. can be difficult in some countries and regions, which means that the application of relay technology can also be effective for urban scenarios. Finally, the group mobility scenario in which relay stations are installed on vehicles like trains and buses to reduce the volume of control signals from moving mobile stations is also being proposed.

In 3GPP, it has been agreed to standardize the relay technology deployed for coverage extension in LTE Rel. 10. These specifications will, in particular, support one-hop relay technology in which the position of the relay station is fixed and the radio access link between the base station and mobile station is relayed by one relay station.

4. Radio Access for Relays

When operating the wireless backhaul link and radio access link on different frequencies, no changes need to be made on the radio interface. Howev-

Table 1 Relay-technology deployment scenarios

Scenario	Deployment	Number of hops
Rural area	Extend coverage to mountainous regions, sparsely populated areas	1 hop
Wireless backhaul	Extend coverage to mountainous regions, sparsely populated areas, remote islands	1 hop, multiple hops
Emergency or temporary coverage	Provide temporary coverage at times of disasters, events, etc.	1 hop, multiple hops
Urban hot spot	Expand coverage and enhance throughput in urban areas with high concentrations of traffic	1 hop
Dead spot	Fill coverage hole	1 hop, multiple hops
Indoor hot spot	Expand coverage to indoor environments and enhance throughput	1 hop
Group mobility	Install relay stations in public vehicles to reduce handover and location-registration control signals	1 hop

*4 **CQI**: An index of reception quality measured at the mobile station expressing propagation conditions on the downlink.

*5 **HARQ**: A transmission technology that resends data for which errors have occurred after error correction and decoding on the receiver side.

*6 **Coupling**: A phenomenon that occurs when signals transmitted from a transmit antenna on radio equipment are received by a receive antenna on the same equipment.

*7 **Isolation**: Completely separates transaction processing from other transactions.

*8 **TDM**: Multiplexing of multiple signal streams in the same radio system band using different times for transmission.

*9 **Femtocell**: A very small area with a radius of several tens of meters covering homes and/or small shops.

er, when operating on the same frequency, the wireless backhaul link and radio access link must be time division multiplexed as described above. The layer 3 relay, moreover, must be able to connect to mobile stations conforming to LTE Rel. 8 specifications, which is a requirement agreed upon in 3GPP. For these reasons, it is mandatory that studies be made on radio interface specifications that take backward compatibility into account. In this regard, the following radio access technology is needed to perform TDM operation between the wireless backhaul link and radio access link.

4.1 Radio Frame Configuration for Relays

In the relay process at a relay station, it is generally desirable that the relay station also transmit reference signals[*10], broadcast channel[*11], synchronization signals[*12], layer 1/layer 2 control signals for uplink control, etc., while receiving signals from the base station on the downlink. However, as described above, controls must be put in place so that transmitting and receiving are not performed simultaneously and sufficient isolation must be achieved between the transmit and receive circuits. To this end, a study is being made on a method that uses the Multicast/Broadcast Single Frequency Network (MBSFN)[*13] sub-frame configuration in the sub-frames received by the relay station for receiving signals from a base station (**Figure 3**)[1]. In this method, a reference signal and layer 1/layer 2 control signals are placed at the very front of the sub-frame taking up only two symbols[*14] at most. With this method, a mobile station can recognize that there will be no transmit data from the relay station for itself in a sub-frame in which the relay station receives signals from the base station. At the same time, the mobile station will be able to measure the quality of the RF signal received from the relay station using the reference signal in the first two symbols at the front of the sub-frame.

5. Radio Protocol for Relays

In layer 3 relay technology, user data is processed at the relay station as described above. It has consequently been agreed in 3GPP that a relay station will be equipped with the same radio protocols as those of an LTE base station [1]. In particular, the relay station will be equipped with the Packet Data Convergence Protocol (PDCP)[*15] for

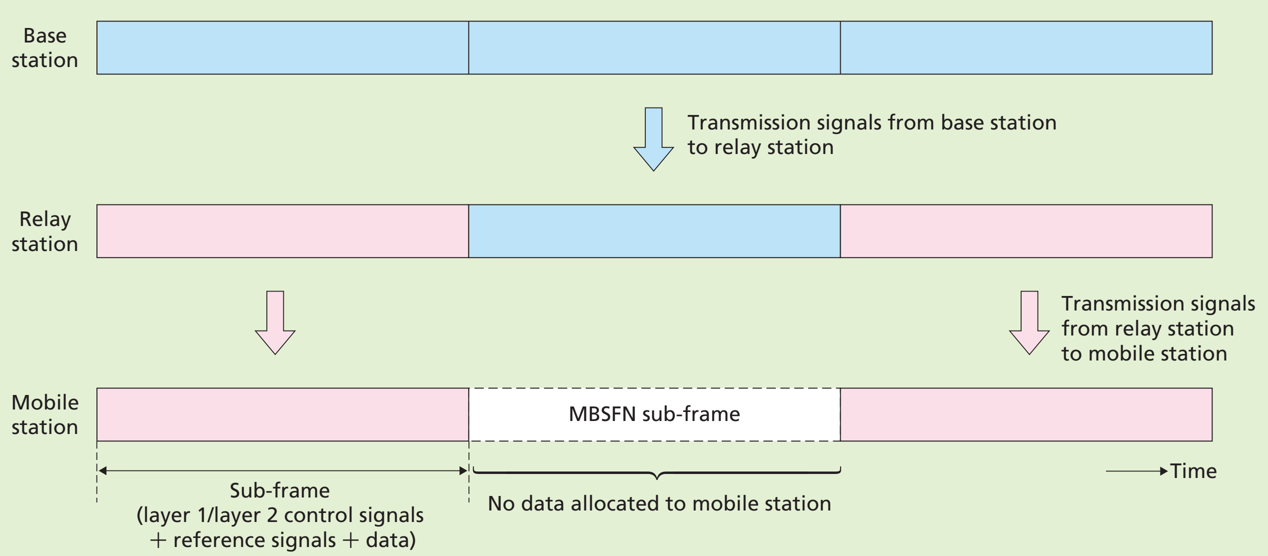


Figure 3 Radio frame configuration for relay transmissions

*10 **Reference signal**: A signal with a predetermined pattern between transmission and reception used on the receive side to estimate channel conditions (amount of distortion and phase rotation).

*11 **Broadcast channel**: A common channel for broadcasting system operation information. A mobile terminal reads this channel on powering up to obtain information needed to begin communications such as operator code, common channel structure, and adjacent cell information.

*12 **Synchronization signal**: A physical signal enabling the mobile station to detect cell frequency, reception timing, and cell ID in order to begin communications when powering up.

user data ciphering and header compression [2], Radio Link Control (RLC)[*16] protocol for retransmission control by ARQ, concatenation/segmentation/reassembly the Service Data Unit (SDU)[*17], and in-sequence packet delivery [3], Medium Access Control (MAC)[*18] protocol for HARQ and user data scheduling [4] and Radio Resource Control (RRC)[*19] protocol for mobility, QoS, and security control [5]. In addition, when operating the wireless backhaul link and radio access link on the same frequency as described above, TDM operation is required between the two links requiring associated radio controls. This can be accomplished by applying a method for allocating resources to the wireless backhaul link.

Methods for applying wireless-backhaul-link resources have been discussed in 3GPP. One of these methods allocates resources to the wireless backhaul link when installing the relay station on the basis of an Operation Administration and Maintenance (OAM) system. Another method allocates radio resources dynamically using signaling and procedures specified in the RRC protocol so that wireless-backhaul-link resources can be used efficiently in accordance with the number of relay stations and traffic volume.

Also being discussed in 3GPP is a method for compressing upper-layer protocol headers such as the IP header when transmitting user data on the wireless backhaul link.

6. Network Architecture for Relays

Since a relay station will have functions corresponding to those of a base station, new studies must be made on control functions and user-data transmission methods that are needed at the interface between the base station and relay station and at the interface between the relay station and a switching station like a Mobility Management Entity (MME) or Serving Gateway (S-GW). In 3GPP, the following requirements as part of architecture studies have been agreed upon.

- Addition of functions to core networks (MME, S-GW) must be minimized
- The interface specified between the switching station and relay station must be provided with the same functions (node-state monitoring, security, etc.) as those of the interface between a switching station and base station specified in LTE.

To satisfy these requirements, it has been agreed that the relay station is to support S1 Application Protocol (S1AP)[*20] [6], which specifies the functions needed between a base station and control switching station (MME) in LTE, and that the protocol is to terminate at a point between the relay station and the control switching station (MME) [7]. The functions of this protocol include those for establishing, modifying, releasing, and handing over the communication circuits transmitting user data (bearer) to the mobile station and those for receiving signals destined for a mobile station in idle state. The radio network architecture for achieving layer 3 relay technology is shown in **Figure 4**. As shown in Fig. 4(a), S1AP is transmitted between the relay station and MME using Stream Control Transmission Protocol (SCTP)[*21] [8] and Internet Protocol (IP). It can be seen here that S1AP is also terminated at the base station connected to the relay station. By having S1AP terminate at a base station in this way, the MME need only establish a communications association for transmitting S1AP only with a base station regardless of the number of connected relay stations. This scheme can be applied to a scenario in which many relay stations are connected to a base station as in an urban area.

Next, as shown in Fig. 4(b), User Plane (U-Plane)[*22] architecture for transmitting user data uses the GPRS Tunneling Protocol User plane (GTP-U) [9] in a manner similar to Control Plane (C-Plane)[*23] architecture to transfer user data to the relay station from the node used for transmitting user data (S-GW). This allows the user-data transfer method between S-GW and base station in LTE to be reused. Between the base station and relay station, moreover, a radio bearer can be established for each QoS requirement

*13 **MBSFN**: A single frequency network for multicasting and broadcasting in which the same signal from multiple cells is temporally synchronized and transmitted.

*14 **Symbol**: A unit of data for transmission. In Orthogonal Frequency Division Multiplexing (OFDM), it comprises multiple subcarriers. Multiple bits (2 bits in the case of Quadrature Phase Shift Keying (QPSK)) map to each subcarrier.

*15 **PDCP**: A sublayer of layer 2. A protocol for ciphering validation, ordering, header compression, etc.

*16 **RLC**: A protocol for controlling retransmission and other functions as a sublayer of layer 2.

*17 **SDU**: In the OSI reference model, a unit of information provided to any protocol layer from an upper layer.

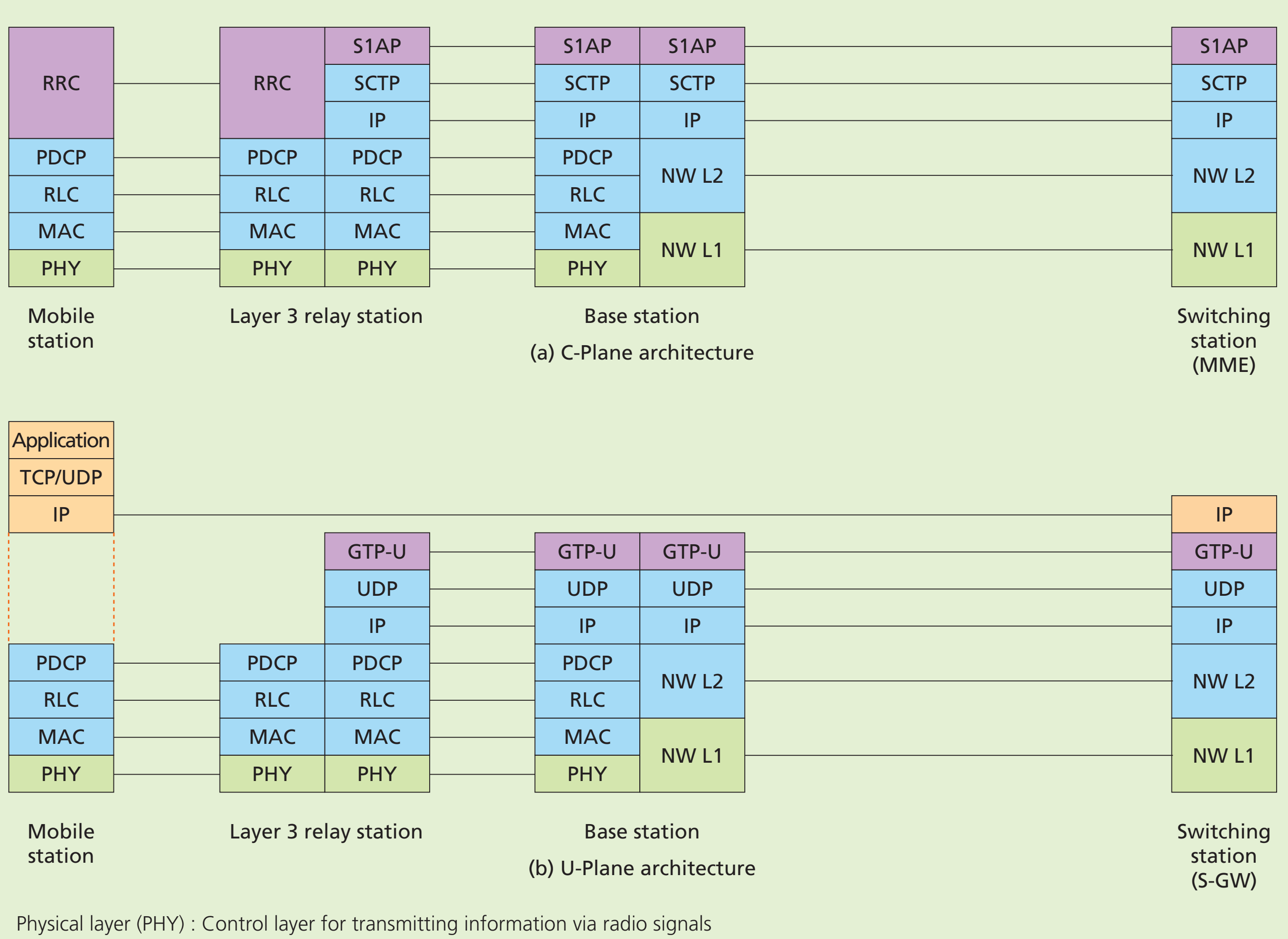


Figure 4 Radio network architecture for achieving layer 3 relay technology

so that user data in services that requires the same QoS for multiple mobile stations can be multiplexed on radio bearers established in this way.

7. Conclusion

This article presented an overview of relay technology now being standardized for the LTE-Advanced system and described deployment scenarios of this technology. Up to now, NTT DOCOMO has been deploying repeaters to extend the coverage area of its 3G mobile communications system to mountainous regions, sparsely populated areas, and remote islands. In LTE, the introduction of layer 3 relay technology instead of repeaters has the potential of mitigating received SINR deterioration caused by inter-cell interference and noise and of achieving a greater throughput-enhancement effect. Going forward, NTT DOCOMO will continue to promote standardization activities toward specifications for effective relay technology in LTE Rel. 10 so that the LTE service area can be extended in an efficient and prompt manner.

References

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[2] 3GPP TS36.323 V9.0.0: "Evolved Universal Terrestrial Radio Access (E-UTRA); Packet Data Convergence Protocol (PDCP) specification," 2009.

*18 **MAC**: The protocol for mapping between the logic and transport channel.
*19 **RRC**: Layer 3 protocol for controlling the radio resources.
*20 **S1AP**: A protocol specifying functions between switching-control equipment and radio base stations for controlling communication circuits that transmit user data to mobile stations, for performing handover, etc.
*21 **SCTP**: A transport layer protocol created to transmit telephone network protocols over IP.
*22 **U-Plane**: The protocol for transmitting user data.
*23 **C-Plane**: The protocol for transmitting control signals.

[3] 3GPP TS36.322 V9.1.0: "Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Link Control (RLC) protocol specification," 2010.

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