The Usage of Relay-aided Communication Techniques in LTE Networks: Layer 3 Relaying

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Abstract

Growth in the mobile communication technology leads to defining the standard to introduce integrable systems. In this paper, necessary requirements determined by 3GPP for mobile communication relay technology has been investigated. In this work, the transmission and receive characteristics, relay types respect to using areas have been expressed based upon E-UTRA Relay radio transmission and reception: TS.36.116 Release 13. Furthermore, simulations are run to measure the bit error rate performance for signals received in both relay and mobile station.

1. Introduction

Several interest groups and standard organizations struggle to determine some specifications with the purpose of obtaining better features such as quality and safety. One of these organizations which design the standards that are used commonly in worldwide is 3^{rd} generation partnership project (3GPP). 3GPP includes cellular telecommunication network technologies such as radio access, core transport network and service capabilities. The standards are also related with the IEEE's Wi-Fi networks. The three technical specification groups in 3GPP are Radio Access Networks, Services & Systems Aspects, and Core Network & Terminals. In this paper, a specification about the relay transmission and reception characteristics of E-UTRA systems which are related to the Radio Access Networks (RAN) group is examined.

1.1. Standardization Development

The historical steps of development of the standardization will given in this subsection. 'Evolved Universal Terrestrial Radio Access (E-UTRA); Relay radio transmission and reception' is a technical specification that was evolved by Ericsson LM, one of the foremost telecommunication companies in the world. The specification is constantly a work in progress through evolution of telecommunication standards, so it is still in the development stage. The first version of the standard was released in October 2010 with the purpose of improving the interface of the 4G technology by using a relay in the transmission and reception processes so that the standard will be commonly used worldwide. Firstly, the abbreviations for relay core specification have been determined to simplify understanding the terms. With version 0.3.0, relay core requirements were added to the specification. After that, performance requirements and relay access link, DL RS power were implemented with 0.4.0. In September 2012, the specification was released and approved, so the version 1.0.0 emerged. From version 11.0.0 to 11.3.0, correction of relay demodulation requirements, relay backhaul link R-PDCCH performance, relay transmitter and receiver requirements, and co-location blocking requirement were determined by the committee, respectively. The committee updated specification to Rel-12 in September 2014. Then, corrections for blocking characteristics and power class for relay backhaul link were implemented between version 12.0.0 and 12.2.0. Requirement description for TS.36.116 was clarified. The correction on the transmitter requirements was added to version 12.2.0. In January 2016, the specification has been updated to Release 13 which is the last version of the specification for now.

2. Relay

In this section, the different relay structures are explained and the comparison between the structures is made. Furthermore, the usage of appropriate relay types is given for different conditions.

2.1. Relay Technologies

The necessity of standardization in order to obtain high data rates in mobile communication has been aforementioned. In addition to data rates, coverage becomes an important issue for cell edge users. Relays enable to extend the coverage efficiently and to increase throughput at the cell edge. Relays can be employed in a different manner according to needs. One of them is the Layer 1 relay, as given in Figure 1, which amplifies the received RF signal from the base station, then transmits the amplified signal to the mobile station. Similarly, the signal captured on the uplink is amplified and transmitted to the base station. It is widely used in 2G and 3G technologies. This technology provides a low-cost solution to send a signal to a mountainous area with a short transmission delay. Because of this simple processing (i.e amplification), short delays occur in the communication process. Although they have positive characteristics such as low-cost implementation and short delay, they amplify inter-cell interference and noise signal with message signal simultaneously. Hence, signal to interference and noise power ratio (SINR) and throughput get worse.

Another relay type decodes and forwards RF signal received from downlink of a base station, which is called the Layer 2 relay. Relay given in Figure 2, first demodulates and decodes the received signal. Then, the relay node encodes and modulates the signal before sending it to a mobile station. This process is performed on the relay in order to overcome the decrease in SINR as a result of amplification. Compared to Layer 1 relay, Layer 2 relay has a better throughput performance due to SINR enhancement. However, processes such as decoding/encoding and demodulating/modulating cause a de-

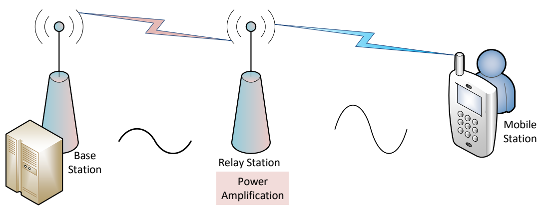

Figure 1. Feature of Layer 1 Relay

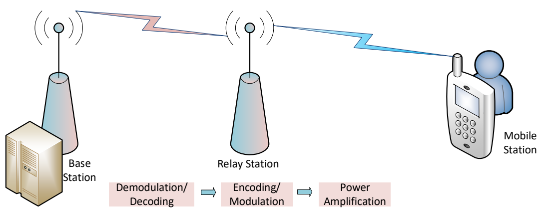

Figure 2. Feature of Layer 2 Relay

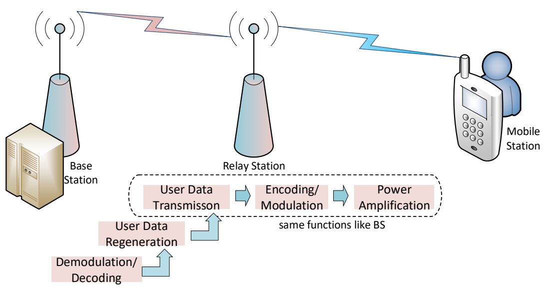

Figure 3. Feature of Layer 3 Relay

lay. Therefore, new radio-control functions are needed to employ this relay type [1].

Similar to the Layer 2 relay, the Layer 3 relay demodulates and decodes RF signal received from the base station. Moreover, it performs user data segmentation to retransmit the signal to the mobile station. Figure 3 depicts the structure of the Layer 3 relay. The related relay eliminates inter-cell interference and noise, then improves the throughput as in Layer 2 relay case. When compared to the Layer 2 relay, the longer delay observe because of this extra processing. As shown in Figure 4, the Layer 3 relay station has unique Physical Cell ID (PCI) on the physical layer [1]. It enables a mobile station to differentiate whether it is a base station cell or a relay station cell. If physical layer control signals such as channel quality indicator (CQI) and hybrid ARQ (HARQ) terminate at the relay station, mobile station recognizes relay as a base station. The frequencies of the wireless backhaul link and radio access link between the relay and mobile station can be different or the same. When using the same frequency, time division multiplexing (TDM) is applied on the wireless backhaul link and radio access link to avoid interfere with each other. TDM does not allow simultaneous transmission and reception in the relay station.

The change on the radio interface is not necessary if the

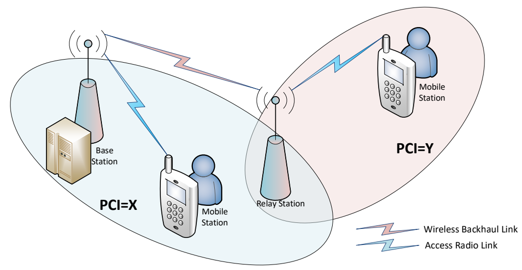

Figure 4. Radio Frame Configuration for Relay Transmission

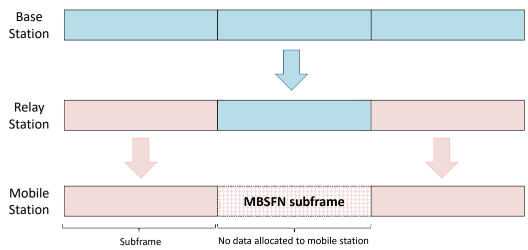

Figure 5. Overview of Layer 3 Relay

wireless backhaul link and radio access link occupy different frequencies. However, when they use the same frequency, TDM is employed for wireless backhaul and radio access links as aforementioned above. The relay node transmits a reference signal when it receives a signal from the base station. As mentioned above, transmitting and receiving are not performed at the same time since making isolation between receive and transmit circuits is not that easy. To avoid interference, TDM is employed; thus, a simultaneous process is not realized. Due to non-simultaneous performance and the necessity of isolation between receiver and transmitter, Multicast/Broadcast Single Frequency Network (MBSFN) subframe is used by relay station to receive signals from base station [1]. When a relay node receives a signal from a base station in a subframe, the mobile station recognizes the absence of data for itself. This phenomenon is visualized in Figure 5.

It should be noted that the transmission rate can be doubled by incorporating different user signals with techniques such as network coding in inter-device (device to device) transmission schemes by using the Layer 3 relay structure. The duplex transmission channel which enables the Layer 3 relay to combine the signals of the different users is given in Figure 6. Here, the relay node sends a combination of two signals instead of sending the signals belonging to different users one by one, thereby increasing the data transmission rate.

2.2. Deployment Scenarios

The deployment of a base station in rural areas or low-dense regions may not be economically acceptable for operators. Instead of braiding of fixed line backhaul links, deployment of

Table 1. Relay Deployment Scenarios

Scenario	Deployment	Number of Hops
Rural Area	Extend coverage of rough area	1 Hop
Wireless Backhaul	Extend coverage of remote islands	1 Hop, multiple hops
Emergency or Temporary Coverage	To supply coverage at the time of emergency like disaster	1 Hop, multiple hops
Urban Hot Spot	Expand coverage and increase 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

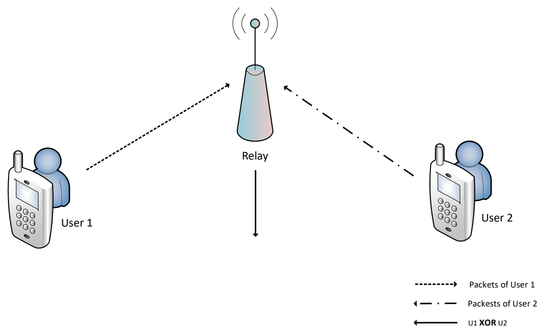

Figure 6. Duplex transmission channel

a relay node is logical for these type areas. The relay station can be employed, because of the difficulty of establishing the backhaul link, for temporary coverage of region in case of an emergency like earthquakes. Besides rural regions, a relay can be favorable for some urban regions that may not be suitable for laying cables or utility poles installation. Some deployment scenarios are given in Table 1 [1].

3. Transmitter Characteristics

In this part, the three main characteristic properties which are valid for single transmitter antenna connector are described. Output power, signal quality, and unwanted emissions are the major features which determine the characteristic of a transmitter. While the rated output power is the mean power level that is declared by the manufacturer, the maximum output power is the mean power level that is measured at the antenna connector for a particular condition during the ON period of the transmitter, where the period is at least 1 sub-frame (1ms). For instance, the maximum output power stays within 2 dB more or less of the rated output power under normal conditions [2]. On the other hand, the mean power in one subframe is called the minimum output power. The transmitter ON/OFF time mask is another important property for dynamics of output power. In general, ON/OFF time mask is the period that is observed between transmitting OFF and ON power and between transmitting ON and OFF power [3]. But, OFF and ON powers are different for the backhaul link, the link between relay and base station, and the access link.

The second crucial property is the signal quality of the transmitted signal. Signal quality is dependent various factors such as frequency error, error vector magnitude (EVM) and time alignment error (TAE). The frequency error is the difference between determined frequency and exact transmitting frequency of the relay node. While the frequency error should remain within ∓ 0.1 PPM region over one period of one slot (0.5 ms) for backhaul link, it should remain within ∓ 0.1 region over one period of one sub-frame (1 ms) for access link [2]. EVM is the difference between measured and ideal symbols after the equalization. EVM can be also expressed as the square root of the ratio between mean error vector power and mean reference power in percent [4]. TAE is the largest time difference between any two signals for any determined set of signals.

Unwanted emissions are another important feature that helps to understand the characteristic of the transmitter. Unwanted emissions contain out-of-band emissions and spurious emissions. Out of band emissions occurs immediately outside of the channel bandwidth due to the modulation process and transmitter nonlinearity. The emission caused from the unwanted effects of the transmitter such as harmonic emissions, parasitic emissions, inter-modulation products and frequency conversion products is called the spurious emission.

4. Receiver Characteristics

In this part, receiver's three major features; the sensitivity level, the dynamic range and the selectivity, are explained. The sensitivity level of a receiver can be expressed differently for backhaul and access links. For the backhaul link, the reference sensitivity power level which is called P_{RS} is the minimum mean power which is applied to the backhaul antenna ports at which the requirements for the specified reference measurement channel are satisfied by throughput. For access link, the reference sensitivity power level (P_{RS}) is the minimum mean power which is received at the antenna at which the requirements for the specified reference measurement channel are satisfied by throughput. For both backhaul and access link cases, the throughput should be more than or equal to ninety-five percent of the maximum throughput of the reference measurement channels [2].

The dynamic range consists of the backhaul link, the maximum input level, and the access link receiver dynamic range. The maximum input level is the maximum mean power that is received from the user equipment at which the throughput is more than or equal to ninety-five percent of the maximum throughput of the reference measurement channel [3]. On the other hand, the dynamic range is the receiver's capability to receive the desired signal in presence of an interfering signal in the received channel bandwidth [4].

The selectivity property includes in-channel selectivity (ICS) and adjacent channel selectivity (ACS). ICS is the ability of the receiver to receive the desired signal when an interfering signal with a larger power spectral density exists. ACS defines the ability of the receiver about receiving an E-UTRA signal at its assigned channel frequency when there is an adjacent channel signal. The ratio between the receive filter attenuation on the assigned channel frequency and the receive filter attenuation on the adjacent channel give adjacent channel sensitivity.

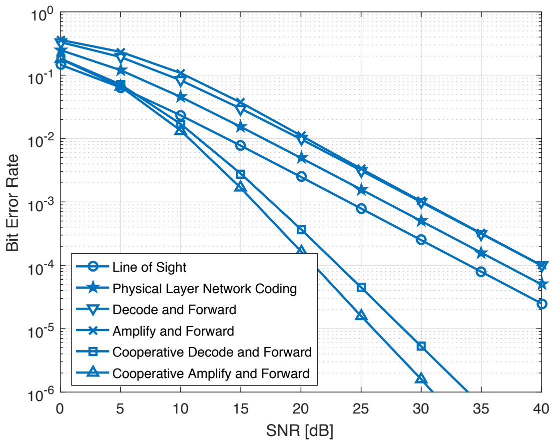

Figure 7. Bit error rate performances in Rayleigh channel for different relay scenarios

5. Simulation Results

Simulations are performed to observe the bit error rate (BER) performances of the various relay protocols. BPSK modulated signal is transmitted from the base station to the relay, then from the relay station to the mobile station. The signal generated at the base station is referenced and the error rates of the signals received at the relay and mobile station are determined. The results obtained in presence of Rayleigh fading channel are given in Figure 7. The performances of the classical transfer and physical layer network coding results are given, as well as the cases where the coherent direct view path is present. When examining the results of classical transmission and physical layer network coding [5], it is observed that the best result is obtained in the case of direct transmission [6]. However, direct transmission is still not standardized. Using relay in situations where direct transmission is not possible improves performance. In this case, the amplify and forward technique provides a relatively better bit error performance at low SNR values than the decode and forward technique. The physical layer network coding result is better than the two techniques. With physical layer network coding, data transmission speed can be doubled (in the case of error-free transmission). In all of these techniques, the diversity gain is equal to 1 because there is a single transmission channel. This result is proved by the slope of the curves as well. In the cooperative amplify and forward and the cooperative decode and forward techniques, there must be a direct route between the transmitter and receiver units. On this count, the diversity gain is equal to 2. Again, in the cooperative case, the amplify and forward technique provides better error performance than the decode and transfer technique.

6. Conclusion

This paper specification describes the minimum requirements for E-UTRA relay transmission and reception. Also, the channel arrangements such as operating bands and channel bandwidths are detailed. Transmitter and receiver characteristics are examined. These characteristics contain output power, output power dynamics, signal quality, undesired emissions, intermodulation for the transmitter and reference sensitivity level, dynamic range, in-channel and adjacent channel selectivity, spurious emissions, intermodulation for the receiver. Then, performance requirements for access and backhaul link are described. It order to obtain a better communication performance, the minimum radio frequency characteristics and the minimum performance requirements of E-UTRA Relay are specified with this standard. The BER performance is examined in the simulation environment for the Layer 3 relay type and the results are given. The simulation results show that although the use of Layer 3 relay type is an enhancement approach, the performance can be further increased in case of relay aided systems with the innovations that direct transmission channel can use.

7. References

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