Adaptive Modulation and Coding for LTE Wireless Communication

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Abstract. Long Term Evolution (LTE) is the new upgrade path for carrier with both GSM/UMTS networks and CDMA2000 networks. The LTE is targeting to become the first global mobile phone standard regardless of the different LTE frequencies and bands use in other countries barrier. Adaptive Modulation and Coding (AMC) is used to increase the network capacity or downlink data rates. Various modulation types are discussed such as Quadrature Phase Shift Keying (QPSK), Quadrature Amplitude Modulation (QAM). Spatial multiplexing techniques for 4×4 MIMO antenna configuration is studied. With channel station information feedback from the mobile receiver to the base station transmitter, adaptive modulation and coding can be applied to adapt to the mobile wireless channels condition to increase spectral efficiencies without increasing bit error rate in noisy channels. In High-Speed Downlink Packet Access (HSDPA) in Universal Mobile Telecommunications System (UMTS), AMC can be used to choose modulation types and forward error correction (FEC) coding rate.

1. Introduction
Long Term Evolution (LTE) is a standard for wireless data communications technology and an evolution of the GSM/UMTS standards. The goals of LTE was to increase the capacity and the speed of wireless data networks by utilizing a new Digital Signal Processing (DSP) techniques and modulations. Adaptive modulation and coding is used to increase the network capacity or data rates [1]. Network architectures used to redesign significantly reduce transfer latency compared to the 3G architectures. The LTE wireless interface is incompatible with 2G and 3G networks, so that it must be operated on a separate wireless spectrum. The physical layer is simulated using Matlab. Channel Quality Information estimation is used to improve the data rates and bit error rate (BER). Various modulation types are discussed.

Increasing broadband multi-media services including VoIP, mobile TV, audio and video streaming, video conferencing, FTP and internet access require larger wireless cellular network and reliability.

Multiple-Input-Multiple-Output (MIMO) antenna systems can provide enormous capacity by spatial multiplexing [2], [3]. The performance of a MIMO system is highly dependent on the characteristics of the matrix channel. Link adaptation can be employed to any time varying systems to improve the transmission throughput by dynamically changing transmission parameters. Therefore the combination of link adaptation and MIMO is promising to realize higher spectral efficiency and higher throughput for mobile communication systems [4].
Fixed modulation cannot make maximum use of information transfer rate to suit changing channel conditions within given bandwidth allocation. Spectral efficiency is the average data rate per bandwidth unit Hertz per cell. Tradeoffs are required in designing mobile communication systems. For a given bandwidth allocation, spectral efficiency can be increased by increasing data rate using higher order modulation or larger multiple-input-multiple-output MIMO techniques. However, this can increase the probability of error in noisy channel.

The problem is to search feasible solution to increase spectral efficiency by matching modulation and coding to conditions on the radio link. Spatial multiplexing techniques for 4×4 MIMO antenna configuration is studied. With channel station information feedback from the mobile receiver to the base station transmitter, adaptive modulation and coding can be applied to adapt to the mobile wireless channels condition to increase spectral efficiencies without increasing bit error rate in noisy channels.

2. System description

2.1. Adaptive Modulation
Modulation is the approach by which a carrier wave has the ability to convey the message or digital signal. There are three essential methods to this: amplitude, frequency and phase shift keying. More bits per symbol or period can be encoded using a high order of modulation. Distinctive order modulation permits to send more bits per symbol and in this way attain higher throughputs or better spectral efficiencies [5]. The utilization of adaptive modulation (AM) permits a wireless system to pick the highest order modulation upon the channel conditions.

2.2. Adaptive modulation and coding
Nowadays, Adaptive Modulation and Coding (AMC) which is a key innovation to progressively respond to the channel change of fading channels [6]. The quintessence of the plan is that, with accessible channel state information (CSI) estimation at the transmitter, link adaptation is empowered by the AMC for compelling usage of the available channel capacity for resulting transmissions while provisioning focused on at the receiver in fighting remote channel fluctuations.

3. Simulation results

3.1. Adaptive Modulation

Figure 1. Physical Downlink Shared Channel Processing.
Figure 1 shows the physical downlink shared channel processing (PDSCH). The Downlink Physical Channel processing using spatial multiplexing codebook-based transmission by firstly scrambling the transport channel encoded bits by a bit-level scrambling sequence. This depends on the physical layer cell identity and ensures the randomization of cells. Secondly, the data modulation is converting the scrambled bits into complex modulated symbols. Layer Mapping is then used to map the complex modulated symbols received. The numbers of layers are same as the number of transmitted antennas. After that, Codebook-based precoding is used to precode the modulated symbols per layer. Then, the resource antenna used to map the precoded symbols are transmitted on each antenna and mapped to the resource elements of the resource blocks available for the transmission. Then, the Cell specific reference signal (CSR) is used to specify number of antenna in a cell and utilized for channel estimation at the receiver. Then, for the resource element carrying the reference signal for an antenna, the corresponding resource elements in other antennas have null transmissions. It permits the CSR signals to transmit without interference from the other antenna transmissions. Then, OFDM transmission is used to create the complex-valued time-domain OFDM signal per antenna from the fully populous resource grid, using the OFDM Modulator block. Then, in the MIMO channel, the higher mobility profiles are avoided as the closed-loop spatial multiplexing mode would be appropriate to high data rate and low mobility situations. Lastly is the Receiver UE processing that comprise of OFDM receiver and MIMO receiver.

The following will cover the channel quality indicator (CQI) channel-state report effect to change the modulation scheme in the subframe. Hence, to understand the design trade-offs, there will be comparison on: firstly, baseline –no adaptation, secondly, random selection of adaptation mode, and lastly adaptive modulation –CQI based.

Figure 2 shows the spectrum of user data acquired from the receive antenna. The receive signal shows the effects of frequency-selective fading effectively balanced by the close-loop spatial multiplexing used in transmission mode. Figure 3 demonstrate the pattern diagrams before (first column) and after (second column) equalization of information achieved from the receive antenna. The receive cluster signal shows that the equalizer can reduce the consequence of fading channel and produce pattern that more closely represents that of the 16QAM constellation.
Table 1 summarize the results for Adaptive Modulation MIMO 4. Table 1 shows that for fixed modulation, a higher modulation order produces higher data rate at the cost of higher BERs. As the modulation change to lower modulation order QPSK, it shows a lower data rate and lower BERs. Moreover, when randomly selecting the modulation scheme with no consideration of channel quality, both the average data rate and the BER are average value.

**Table 1. Adaptive modulation MIMO 4×4.**

| Type of Modulation | Average Data Rate (Mbps) | Modulation Rate | Coding Rate | Bit Error Rate (BER) |
|--------------------|--------------------------|-----------------|-------------|----------------------|
| QPSK               | 57.34                    | 2               | 0.5         | 0.00001              |
| 16QAM              | 112.4                    | 4               | 0.5         | 0.12183              |
| 64QAM              | 157.43                   | 6               | 0.5         | 0.21584              |
| Random selection   | 102.214                  | 2 or 4 or 6     | 0.5         | 0.11461              |
| Adaptive Modulation| 99.24                    | 2 or 4 or 6     | 0.5         | 0.11239              |

For AM scheme with channel quality estimation, the result comes out close to random selection. Random Selection scenario has data rate of 102.214 Mbps and BER of 0.11461 while for AM these are 99.24 Mbps and 0.11239 for data rates and BER respectively. Thus Adaptive Modulation can ensure a high data rate at reasonable Bit Error Rate compared to fixed modulation.

### 3.2. Adaptive modulation and coding

CQI channel-state report effect is used to modify the modulation scheme and coding rate in the sub-frame. Hence, to understand the design trade-offs, comparison is based on the baseline—no adaptation simulation and comparing the result with the random changing of both adaptive modulation and coding rate simulation.
Figure 4 demonstrates the spectrum acquired from the receive antenna in a subframe for adaptive modulation and coding rate. The receive signal shows the impact of frequency-selective fading effectively balanced by the close-loop MIMO spatial multiplexing.

Figure 5 demonstrates the pattern diagrams before (first column) and after (second column) equalization of data achieved from both of the receive antenna. The cluster region before equalization scatters farther than the constellation point. However, after equalization, the cluster region starts to surround the nearest constellation point. The received cluster signals form a smaller square region.

Table 2 shows the results for MIMO 4x4 simulation for AMC. For fixed modulation, a higher modulation order produces higher data rate at the cost of higher BERs. However, when switching to random modulation selection, it gives the average results of the three fixed modulation cases (QPSK, 16QAM, and 64QAM).

![Figure 4. Adaptive modulation and coding based on CQI feedback, MIMO 4x4 antennas: transmitted and received signal spectrum, PSD (dB) versus Frequency (MHz).](image)

![Figure 5. Adaptive modulation and coding based on CQI feedback, MIMO 4x4 antennas: pattern diagram before and after equalization, left (before equalization), right (after equalization).](image)
Table 2. Adaptive modulation and coding MIMO 4×4.

| Type of Modulation          | Average Data Rate (Mbps) | Modulation Rate | Coding Rate | Bit Error Rate (BER) |
|-----------------------------|--------------------------|-----------------|-------------|----------------------|
| QPSK                        | 57.34                    | 2               | 0.5         | 0.00001              |
| 16QAM                       | 112.4                    | 4               | 0.5         | 0.12183              |
| 64QAM                       | 157.43                   | 6               | 0.5         | 0.21584              |
| Random selection            | 130.91                   | 2 or 4 or 6     | 0.4958      | 0.18133              |
| Adaptive Modulation and Coding | 85.83            | 2 or 4 or 6     | 0.39-0.5    | 0.08375              |

For AMC, with channel quality estimation, the result comes out close to Random Selection. Random selection scheme has data rate of 130.91 Mbps and BER of 0.18133 while for AMC these are 85.83 Mbps and 0.08375 for data rates and BER respectively. Proportionally, by using a calculation:

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\frac{85.83}{99.24} \times 0.11 = 0.0972
\]

By comparing with the value in Table 1 and Table 2, the pro rata value obtained is 0.0972. The BER in adaptive modulation and coding is 0.08375 which is lower than the proportional value (0.0972). Thus AMC can further reduce BER compared to AM.

Overall, the CQI estimation techniques have been implemented and it also proves that AMC can increase data rate or spectra efficiency and reduce bit error rate better compared to fixed modulation. The user data rates and efficiency spectrum can be altered by using the selection measures for link adaptation. The main objective of LTE to experience high speed and high capacity can be easily achieved by using these techniques thus providing a faster and better performance.

4. Conclusion

Adaptive Modulation and Coding can increase data rate or spectra efficiency and reduce BER better compared to fixed modulation.

References

[1] Yamindi J-B, Hong J and Wu M-Q 2012 The optimization capacity of the MU-MIMO with channel quality information IEEE 16th International Symposium on Consumer Electronics (ISCE) pp 1-5 doi: 10.1109/ISCE.2012.6241685

[2] Foschini G J and Gans M J 1998 On limits of wireless communications in a fading environment when using multiple antennas Wireless Personal Comm. vol 6

[3] Telatar E Capacity of Multi-Antenna Gaussian Channels June 1995 Technical Report, AT&T Bell Labs

[4] Catreux S, Gesbert D and Heath R W June 2002 Adaptive modulation and MIMO coding for broadband wireless data networks IEEE Commun. Mag. vol 40 pp 108-115

[5] Goldsmith A J and Chua S-G 1999 Adaptive modulation and coding for fading channels Proc. IEEE Information Theory and Communications Workshop pp 24-26 doi: 10.1109/ITCOM.1999.781396

[6] Sharma A and De S November 2011 Exploiting fading dynamics along with amc for energy-efficient transmission over fading channels IEEE Communications Letters 15 pp 1218-20 doi: 10.1109/LCOMM.2011.090911.111472