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*Research Article*

# The Study of Indoor and Field Trials on $2 \times 8$ MIMO Architecture in TD-LTE Network

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With the development of mobile internet service, long-term evolution (LTE) system was proposed in the third generation partnership project (3GPP) to provide higher data rates and frequency efficiency. Since the year of 2010, 113 LTE networks have been commercially deployed worldwide, and most of the networks are based on frequency division duplexing (FDD). In this paper, measurement methods of four MIMO transmission modes (TMs) in time division-LTE (TD-LTE) are studied and analyzed. Link level simulation is carried out to evaluate the downlink throughput for different signal-to-noise ratios and parameter settings. Furthermore, indoor and field tests are also presented in the paper to investigate how real-world propagation affects the capacity and the error performance of MIMO transmission scheme. For the indoor test, radio channel emulators are applied to generate realistic wireless fading channel, while in the field trials, a live TD-LTE experiment cellular network is built, which contains several evolved nodeBs (eNBs) and a precommercial user equipment (UE). It is shown from both simulation and tests results that MIMO deployment gives a substantial performance improvement compared with the third generation wireless networks.

## 1. Introduction

The deployment of long-term evolution (LTE) radio access technology, defined by the third generation partnership project (3GPP) specification [1–3], is currently ongoing on a broad scale. Based on the global mobile suppliers association's report [4], since the first LTE network was built in the year of 2009, 113 commercial networks have been deployed in 51 countries. Most of current LTE networks use paired spectrum frequency, which means that uplink and downlink transmissions are allocated in two different frequency bands. However, due to the lack of frequency resource and the characteristic of asymmetric data services, time division-LTE (TD-LTE) draws lots of attentions worldwide, especially in China. TD-LTE is an integral part in the 3GPP standards and can provide an evolutionary roadmap for TD-synchronous code division multiple access (TD-SCDMA) systems [5–7]. China Mobile, which is the biggest network operator in China, announced that the TD-SCDMA sites and other elements, for example, antenna, radio frequency, and so forth, can be reused in the TD-LTE, so the cost of building a new TD-LTE network will be reduced. In order to verify the performance of TD-LTE network, three steps were scheduled before commercial deployment. Firstly, basic architecture and transmission function were analyzed and evaluated by the simulation. Meanwhile, several indoor experiments were accomplished. Secondly, in the large scale trials (Phase I) during 2011, China Mobile built 850 base stations in 6 cities to verify the performance of key techniques in TD-LTE system, involving network equipments, mobile devices, and chipsets. In addition, the following Phase II trials extend the number of experiment cities to 13 and 7 system manufactures participate in the project. The indoor and field test environments discussed in this paper belong to these trials.

Indoor and outdoor trials are a promising way to evaluate the performance of a new system. Extensive literatures have been published to discuss LTE experimental methods and results [8–11]. In [8], dual-antenna design was investigated in lower carrier frequencies, for example, band 13 (746 MHz–756 MHz). Field trials in that paper are based on the 2 × 2 multiple-input multiple-output (MIMO) precommercial LTE network, that is, two receive branches at the user equipment (UE) and two transmit branches at the base station. In addition, the authors in [9] extended the number of transmission antennae to four and the carrier frequency was set in band 38 (2570 MHz–2620 MHz). The trial results show that the close-spaced copolarized configuration provides the best performance for the users with poor channel condition, while dual-polarized and large-spaced antenna configuration is suitable for the users at the cell center. Recently, with the development of wireless techniques, LTE-advanced (LTE-A) has been widely discussed [10, 11]. The closed-loop single user-MIMO (SU-MIMO) transmission was evaluated under adaptive modulation coding (AMC) combined with carrier aggregation in the LTE-A uplink [10]. Cross-polarized antenna configuration and the influence of slanted angles for the UE were considered. By employing uplink 2 × 2 SU-MIMO, the average throughput is increased by 60% compared to the 2 × 1 antenna architecture. Downlink performance of LTE-A was discussed in [11], which clarified the relationship between modulation schemes and antenna polarization. According to the trial results, copolarized antenna is suitable for 16QAM while 64QAM can achieve better throughput with dual-polarized antennas. However, all the field trials mentioned perviously are based on the frequency division duplexing (FDD) LTE network. To the best our knowledge, there is no previous work referring to the TD-LTE test methods and results in both indoor and outdoor scenarios.

In this paper, we focus on the performance comparison of different transmission modes (TMs) in TD-LTE downlink, where 2 × 8 antenna configuration is verified by link level simulation, indoor emulation, and field tests. Firstly, average throughput versus different signal-to-noise ratio (SNR) is given in two typical channel models, that is, spatial channel model extended (SCME) [12–14] and international mobile telecommunication-advanced (IMT-A) models [15, 16]. Then, in our indoor lab, base station and UE are connected via the radio channel emulation equipment to analyze TD-LTE MIMO performance in the fading environment. By utilizing channel emulators, instant fast fading channel impulse responses are built for both uplink and downlink, and noise is added according to the input setting parameters. After the stages of simulation and indoor experiments, field trials are performed in a TD-LTE precommercial network. The test results show that the spectrum efficiency and the cell coverage of TD-LTE system are similar to that of FDD-LTE system.

The paper is organized as follows. In Section 2, the MIMO transmission modes utilized in TD-LTE are described, and the link level simulation assumptions and results are given. Then, indoor experiment is presented, and two channel models, that is, SCME and IMT-A, are discussed in Section 3. In Section 4, field trial methods and results are provided. Finally, we conclude the paper in the Section 5.

## 2. Analysis and Simulation for MIMO Transmission Modes

In LTE system, independent data steams (codewords) are mapped onto one or two layers, and then the layer mapping is performed based on the precoding scheme [2, 3]. There are 8 transmission modes defined in 3GPP release 9 for LTE downlink [1], (1) single transmit antenna, (2) transmission diversity, (3) open loop spatial multiplexing with cyclic delay diversity (CDD), (4) closed loop spatial multiplexing, (5) multiuser MIMO, (6) closed loop spatial multiplexing using a single transmission layer, (7) beamforming, and (8) dual layer beamforming.

Transmission modes 1 and 7 are identical from the UE perspective, where single layer transmission is adopted. TM1 only uses one antenna for downlink transmission, while beamforming technique is adopted in TM7 to make full use of multiple antennas at the base station. Therefore, diversity gain and array gain can be achieved. Meanwhile the computational complexity at UE does not increase, because the mobile device appears to receive only one transmit antenna and the actual number of antennas cannot be seen at the UE side. Transmit diversity is observed as a fallback option for some transmission modes due to its robustness. TM2 is suitable to be deployed at the access procedure and data transmission when channel condition is not satisfied. If the base station has two antennas, space frequency block code (SFBC) is adopted, while for four antennas scenario, a combination of SFBC and frequency switched transmit diversity (FSTD) is applied. In the TM6, downlink channel quality is fed back to the base station and the transmission layer is still restricted to one. In order to increase the capacity, two codewords can be supported for transmission modes 3, 4, 5, and 8. In the TM3, if the rank is greater than one, the signal is supplied to each antenna with a specific delay. No feedback is required before precoding, except for the rank indicator (RI). Transmission modse 4 and 8 can be observed as the enhancement of transmission modes 6 and 7, respectively. Based on the UE feedback precoding matrix indicator and RI, two data stream transmission is achieved in the closed loop multiplexing. Two layers are configured at the base station in the TM8 so that the beamforming and multiplexing can be combined for one or two UEs. MU-MIMO implement is defined in mode 5 where two users can be scheduled in the same resource block. In TD-LTE network, we mainly focus on the transmission modes 2, 3, 7, and 8. Moreover, mode adaptation is considered in the practical deployment. When the channel condition is good enough, two data streams, that is, transmission mode 3 or 8, are adopted to improve system throughput, while for the users at the cell edge or experiencing long-term deep fading, transmit diversity and beamforming are selected to provide diversity gain.

In order to evaluate the performance of the previous MIMO transmission modes, reliable measurement-based channel models are needed, which have to be accurate because the wireless propagation environment has a significant impact on the network throughput. In this paper, SCME none LOS (NLOS) [12–14] and IMT-A urban macro (UMa) line-of-sight (LOS) [15, 16] channel models are exploited for MIMO performance evaluation and comparison. There are twelve clusters in the IMT-A UMa LOS channel model, and each cluster contains twenty rays. For the two strongest clusters, rays are divided into three subclusters with fix delay offsets. For SCME channel model, there is no LOS cluster, because the blocking impact caused by the buildings is assumed in between the base station and UE. There are six clusters in the channel model. Each cluster can be divided into three subgroups. Twenty rays are allocated in these subgroups based on the specific order, which is clarified by [15]. It is noted that doppler frequency shift, multipath, and the correlation between multiple antennas are all considered in these small-scale fading models.

In this session, the downlink performance of TD-LTE network is evaluated by the link level simulation. The base stations are equipped with eight antennas, and UE has two antennas for downlink receiving because of the size limitation and the cost. However, only one primary antenna at the UE is allowed for uplink transmission. The same antenna architecture is assumed in [17]. Average throughput of transmission modes 2, 3, 7, and 8 is presented and compared versus different SNR region. Three bands have already been allocated to China mobile for TD-LTE application, which can be classified by band 38, band 39, and Band 40. band 38 and band 39 will be utilized for outdoor deployment, while band 40 is suitable for the indoor hotspot coverage. During the simulation, band 38, where the center frequency is 2.6 GHz, is adopted with 20 MHz bandwidth. The special subframe configuration 7 is applied, while uplink-downlink configuration type 1 is supported. For simplicity, normal cyclic prefix is assumed. In order to meet the requirement of fast fading channel, adaptive modulation and coding (AMC) and hybrid automatic repeat request (HARQ) are introduced in the simulation platform. Turbo coding is utilized to combat the long-term deep fading, and the max-log-map decoding algorithm is accomplished. Interstream interference and noise are eliminated by minimum mean square error (MMSE) detection at the receiver [16]. Due to the fact that the channel reciprocity is obtained in the TD-LTE, the downlink beamforming is based on the uplink channel estimation. We assumed that the ideal reciprocity is applied in the simulation, where the beamforming matrix is perfectly matched to the downlink channel propagation characteristic. Detailed assumptions and parameters are listed in Table 1.

The average downlink throughput for IMT-A and SCME channel models is given by Figures 1 and 2, respectively. As can be seen from the link level simulation results, at the low SNR region, the average throughput is nearly the same for all transmission modes. Since the transmission modes 3, 7, and 8 can fall back to SFBC if the channel condition is unsatisfied, diversity gain is provided to eliminate the impact of the noise. As the SNR increases, the performance gap for different velocity is enlarged due to the doppler frequency shift. When SNR is equal to 28 dB, the average downlink throughput is approximate to the peak rate for transmission mode 2 and 7. Due to the interference between two data streams, downlink throughput of transmission modes 3 and 8 is significantly decreased with high speed. Particularly for the TM7 and TM8, the downlink precoding is based on the uplink channel estimation in the previous frame. Therefore, if the channel impulse response rapidly changes in the time domain, the advantages of beamforming technique will be vanished. The throughput with low speed for TM8 outperforms TM3 in most SNR regions, but the peak rate is slightly lower because of the signaling cost. Since the multiplexing gain is obtained, the throughput of transmission modes 3 and 8 is increased by 60% compared with that of transmission modes 2 and 7 at the high SNR region.

Table 1: Simulation parameters.

| Parameters | Assumptions |
|---|---|
| No. of eNB antennas | 8 |
| No. of UE antennas | 2 |
| Transmission mode | 2, 3, 7, and 8 |
| Bandwidth | 20 MHz |
| Channel reciprocity | Ideal |
| Uplink and downlink configuration | 1 |
| Special subframe configuration | 7 |
| MCS selection scheme | 10% initial BLER |
| Fast HARQ scheme | Chase combining |
| Traffic model | Full buffer |
| Channel estimation | Ideal |
| Detection algorithm | MMSE |
| Scenario | Urban macro |
| Channel model | SCME and IMT-A |
| UE speed | 3 km/h, 30 km/h and 120 km/h |

## 3. Indoor Experiment of Downlink Performance

After the stage of simulation, where key techniques of MIMO architecture have been verified, indoor experiment needs to be addressed to examine the TD-LTE function and performance before the field trials. Some interoperability test (IOT) items are also included in this stage. However, we mainly focus on the downlink average throughput of transmission modes 2, 3, 7, and 8 in this section. In our indoor laboratory, a single precommercial network system is employed, which contains core network, a building base band unit (BBU), and a radio remote unit (RRU). The maximum of transmission power in each antenna port is 0 dBm, and other detailed parameter settings are listed in Table 1. A TD-LTE release 9 based universal serial bus (USB) dongle performs as the receiver. The RRU and USB dongles are connected via radio channel emulators, which are applied to generate accurate and realistic channel fading. In order to compare the results between the simulation and indoor test, SCME and IMT-A channel models are adopted by the channel emulator.

As depicted in Figure 3, eight cross-polarized antenna ports at the RRU are connected to the downlink channel emulator by the cable lines, and $2 \times 8$ MIMO channel fading is added, where multipath fast fading, doppler frequency

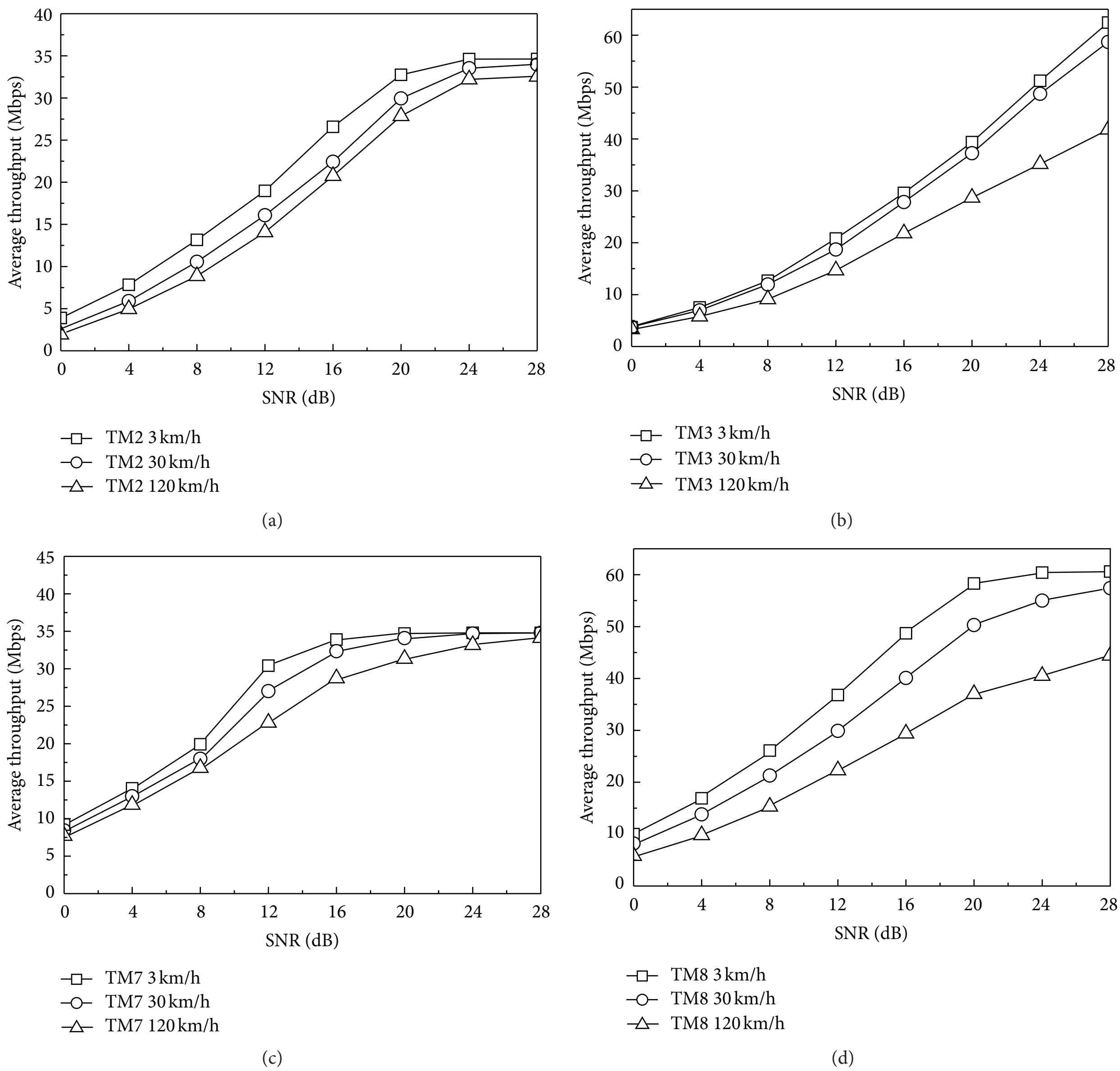


Figure 1: The downlink average throughput for IMT-A NLOS.

shift, and the spatial correlation between multiple antennas are considered. Additive white Gaussian noise (AWGN) is combined in the output signals at the emulator, and the noise power is based on the SNR settings. The USB dongle detects the desired downlink information and feeds back the acknowledgements (ACKs) or negative acknowledgements (NACKs). It is noted that although two antennas are deployed at the UE, only one main antenna is allowed for uplink transmission. Due to the fact that TDD mode is applied, the signals for both uplink and downlink should experience the same channel fading. A single channel emulator can be utilized to evaluate the performance of open-loop MIMO scheme, for example, SFBC and CDD, but for the TM7 and TM8, where downlink beamforming vector is based on the uplink channel estimation, two channel emulators are needed to separately emulate the uplink and downlink channel fading. Moreover, in order to obtain the channel reciprocity of TDD mode, the uplink and downlink channel emulators should be synchronized and can simultaneously play the same channel models. After the random access procedure, a file transfer protocol (FTP) client is used to download several large files. The average throughput for each selected SNR value is calculated during 5 min. The downlink average throughput of transmission modes 2, 3, 7, and 8 for SCME and IMT-A channel model is given in Figures 4 and 5, respectively.

As depicted in Figures 4 and 5, the throughput for TM2 is almost the same for the three types of velocity, since the diversity gain is obtained to decrease the impact of doppler frequency shift. At the high SNR region, the three curves

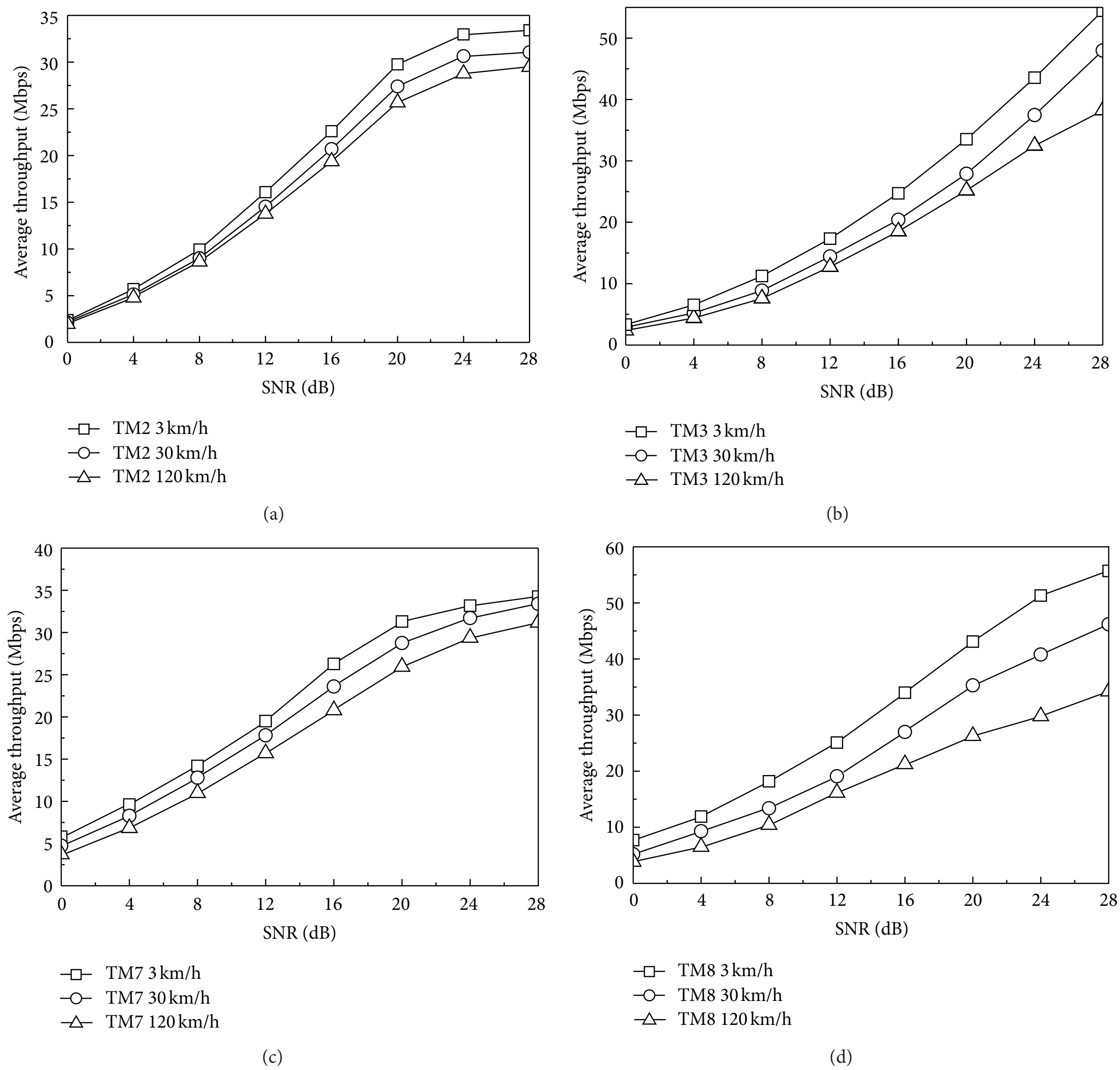


Figure 2: The downlink average throughput for SCME LOS.

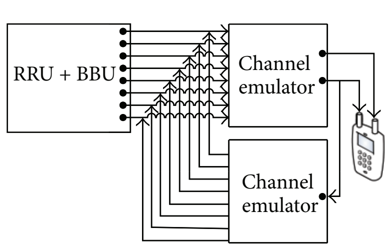


Figure 3: The indoor test scenario.

of TM2 overlap, because the peak rate can be achieved. The throughput of TM3 outperforms TM2 significantly, if the channel condition is qualified to support two data streams. However, the performance enhancement of TM3 in the indoor test is lower than that in the simulation, because the channel emulator is employed to formulate the complex wireless channel propagation. Both the interference between the multiple antennas and the noise are introduced by the channel emulator. TM7 and TM8, where the beamforming scheme is applied, are more sensitive to the velocity. The reason for this is that the downlink beamforming precoding matrix is based on the uplink channel estimation. If the channel experiences rapidly time varying, the beamforming gain will vanish. As the velocity increases, the throughput of TM8 is lower than that of TM3. Moreover, the performance improvement of TM8 is vanished when the velocity is equal to

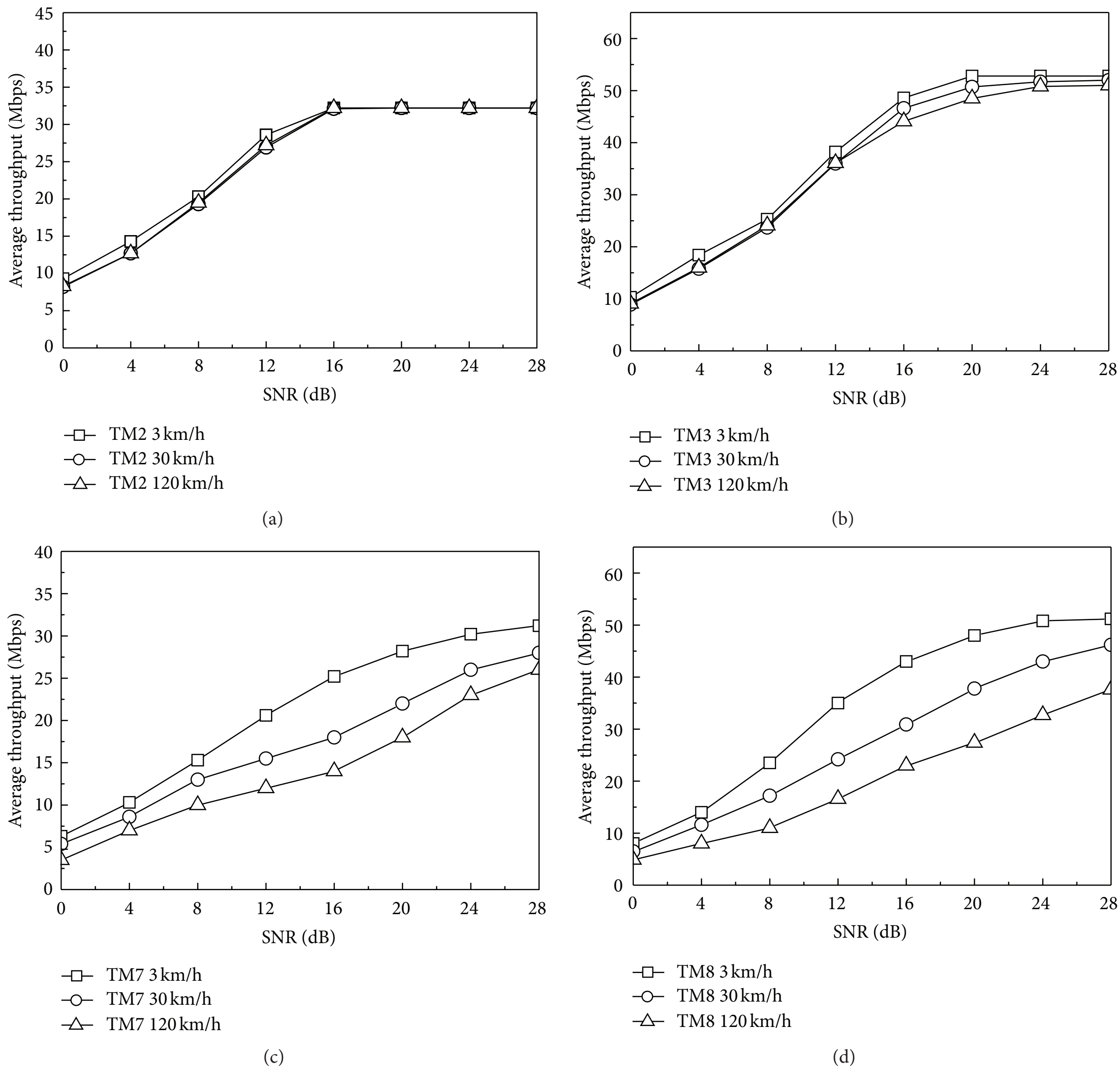


Figure 4: The average throughput for IMT-A based on the indoor experiment.

120 km/h. Because of the diversity gain provided by the SFBC and the well optimization at the UE, the throughput of TM2 and TM3 for different speed is almost the same.

## 4. Field Trial Setup and Measurement Results

In this section, field trials are performed to further investigate the performance of different MIMO transmission modes in TD-LTE system. In the experiment network, band 38 is implemented with 20 MHz bandwidth to evaluate the downlink average throughput for the transmission modes 2, 3, 7, and 8. The radio environment is selected as similar as possible to what UEs will experience in a commercial network. For this purpose, the field trial was conducted in Huai Rou district, a typical urban macroscenario near Beijing, China. This area contains several blocks, where almost all of the buildings have five or six floors. There are five base stations deployed in this area, and about ten sectors are located in the trial route. The base station antenna radomes are installed on the roofs near the trial streets. Each antenna radome has four linearly ordered columns with a horizontal spacing of 0.7 $\lambda$ ($\lambda$ represents the wavelength). In each column, a colocated antenna pair is adopted, which is cross-polarized by $\pm 45^{\circ}$ from the vertical. USB dongle employs two antennas for downlink reception and only uses a single main antenna to transmit uplink messages. The maximum of downlink common reference signal (CRS) power and total uplink transmission power is set to 15 dBm and 23 dBm, respectively. Moreover, closed-loop power control algorithm

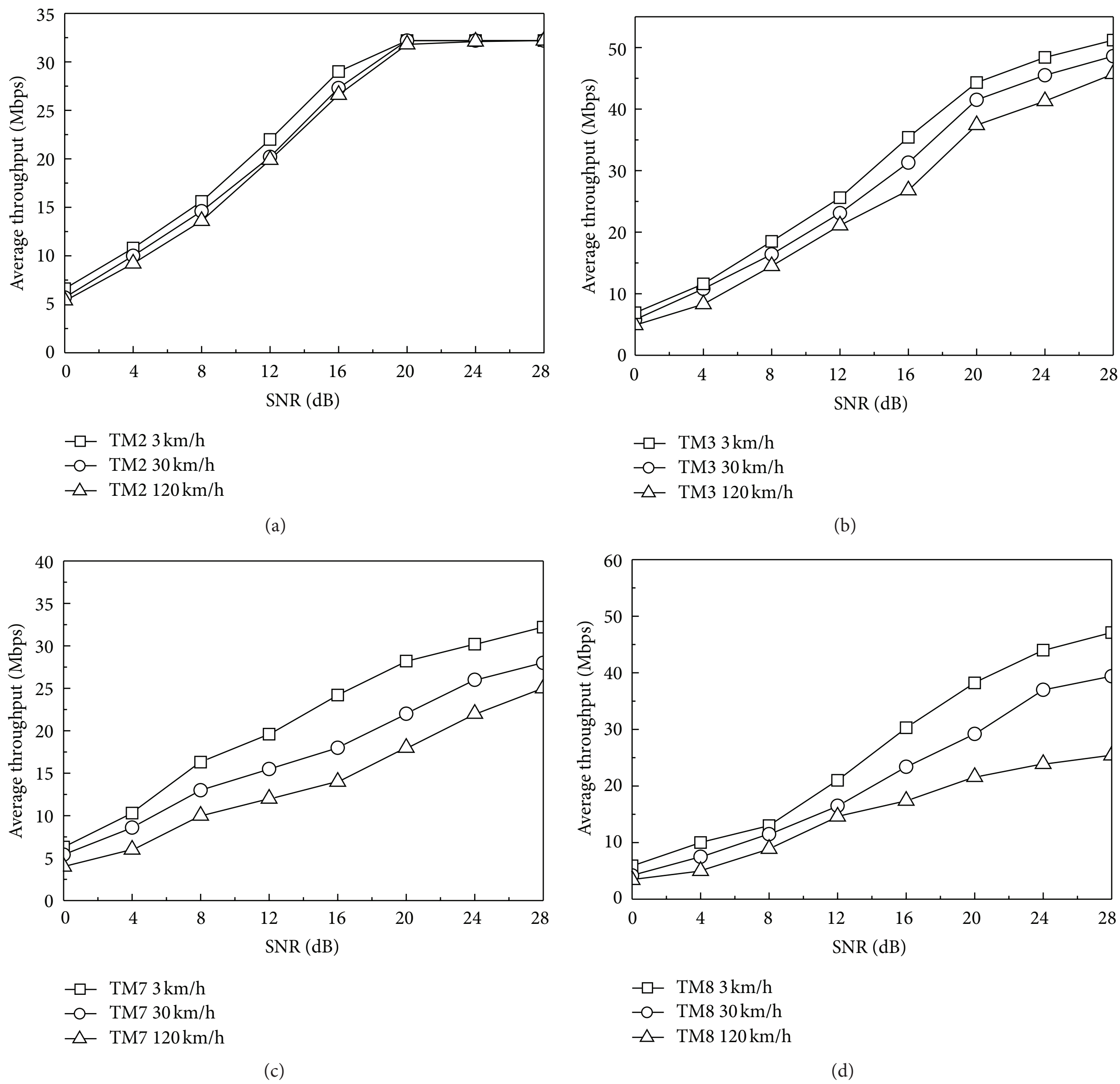


Figure 5: The average throughput for SCME based on the indoor experiment.

is introduced in the uplink to overcome the impact of pathloss and shadow fading. AMC and HARQ are also applied in the network to improve downlink throughput. The UE capability is restricted to the category 3.

Field trials presented in the paper include two items, that is, stationary testing and mobility testing. In the stationary test case, the post-SNR (SINR) is reported by the UE after joint detection. Nigh fixed locations, where the SINR is approximate to the SNR settings in the simulation and indoor experiments, are selected in a single sector. Because the target SINR points are ranging from 0 to 25 dB, the distance between the serving base station and USB dongle is approximately from 50 m to 400 m. In the high SINR region, a direct LOS radio propagation is selected, while in order to measure the UE capacity in low SINR region, NLOS channel condition is adopted, which is generated by the surrounding office buildings which are five or six floors high between the transmitter and receiver. In each selected SINR location, USB dongle is attached in the network and downloads FTP files during five minutes. Average throughput is calculated and compared for different transmission modes (Table 2).

As depicted in Figure 6, the downlink throughput for different transmission modes is evaluated under nigh fixed locations. In the low SINR region, that is, 0 dB, the four transmission modes have similar performance. As the SINR increases, the TM3 and TM8 outperform TM2 and TM7 due to the multiplexing gain. The beamforming technique, which is adopted by the TM7 and TM8, can improve the throughput significantly if the SINR is lower than 12 dB. However, the peak rate of TM3 is slightly higher than that

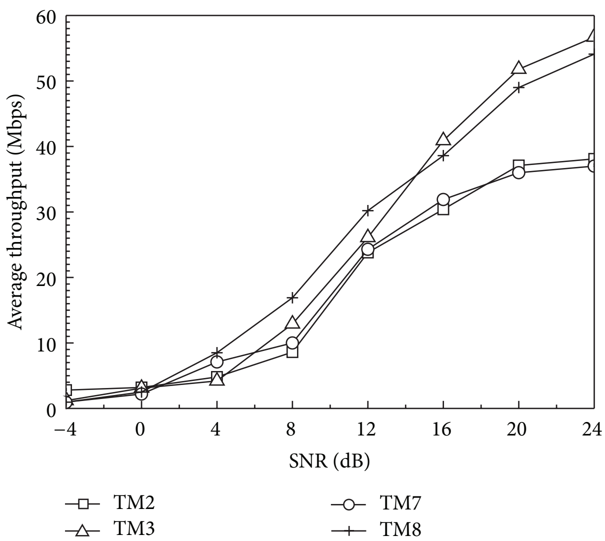


Figure 6: The downlink average throughput in the field trail.

of TM8 owing to the less signalling cost. Although complex radio propagation is provided by the field trail, the data rate of TM3 is approximate to 60 Mbps when SINR is equal to 24 dB. If the SINR is higher than 20 dB, the peak rate of TM2 and TM7 is achieved. It is noted that in each selected location, the test vehicle will not move while the test UE downloads the files. Hence, the doppler frequency shift is small and the beamforming performance enhancement is more remarkable.

For the mobility testing, a drive route is carefully designed to go cross all the ten sectors, and the maximum distance between the base station and UE is approximately 500 m. The terrain is generally flat and dominated by the five or six floored buildings. In the experiment route, both high and low SINR regions are included, and the reference signal receiving power (RSRP) levels are ranging from −65 dBm to −110 dBm. Due to the varying radio environments, a wide range of channel characteristics appear, which contain both LOS and NLOS channel models. The USB dongle was placed in the vehicle and the drive speed was mostly under 30 km/h. If the UE is moved to the edge of serving cell, handover or cell reestablishment is executed depending on the network coverage. The measurement route takes 20 minutes for one lap. It is noted that the style of the testing vehicle and the traffic in the street are probably important aspects for the performance evaluation. Hence for each experiment item, we take 2 hours to obtain average downlink throughput meanwhile at least 5 laps driving along the route are needed. Two MIMO architectures are included in the mobility test, that is, (1) transmission modes 2, 3, and 7 adaptation as well as (b) transmission modes 2 and 8 adaptation. Base station selects the specific transmission mode to meet the varying channel quality in the route. For the trial case (1), CDD is configured by the serving cell to support two data streams transmission. As the SINR and RSRP decrease, SFBC or beamforming is adopted to provide diversity gain. For the trial case (2), if the channel condition is qualified,

Table 2: Average throughput in the test route.

| Transmission mode | 2/3/7 adaptation | 2/8 adaptation |
|---|---|---|
| Average throughput | 9.87 Mbps | 9.72 Mbps |

transmission 8 is used to achieve both beamforming gain and multiplexing gain in case (2).

In the mobility testing, the downlink throughput of TM2/3/7 adaptation and TM2/8 adaptation is almost the same. Mode adaptation is applied here to allow the base station to switch the transmission mode based on the channel condition. Since the poor coverage at the cell edge and the doppler frequency shift decrease the performance, the average throughput in the field trail is about 10 Mbps, which outperforms the third generation wireless system significantly [18, 19]. It is noted that the field trail route and the algorithm adopted in the base station and the UE may impact the performance; our test conclusion shows high reproducibility.

## 5. Conclusion

In this paper, we firstly give a brief introduction of different transmission modes, especially focusing on the those utilized in the TD-LTE network. Link level simulation is carried out to evaluate average downlink throughput. Then, indoor experiments are applied by employing the channel emulator. Two channel models, that is, SCME and IMT-A, are adopted in both simulations and indoor tests. In order to verify the performance enhancement of MIMO architectures in a live TD-LTE network, field trials are conducted in Huairou district, Beijing, China, which is a typical urban macroscenario containing ten sectors in the whole area. Stationary testing and mobility testing are included in the field trials. Downlink throughput for each transmission mode is obtained in the fixed location according to the UE received SINR. Furthermore, a drive route is carefully designed to go across the whole TD-LTE coverage area. Two MIMO adaptation schemes are analyzed and compared in the mobility testing. Because the vehicle type and the traffic in the street may impact the experiment results, we take two hours to obtain the average throughput. It is shown from the experiment results that TD-LTE system can provide similar performance compared with FDD-LTE and outperforms the third generation wireless networks significantly.

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