APPLICATION NOTE

Link-Level Simulation with LTE Toolbox

MathWorks®

Throughput Analysis of LTE and LTE-A Transmission Modes

This application note shows how you can use *MATLAB*® and *LTE Toolbox*™ to analyze the throughput of the transmission modes (TMs) specified in LTE and LTE-A.

LTE is a flexible system that offers a number of TMs. The following TMs are supported in Release 12 of the LTE standard:

- TM1: Single antenna (Port 0)
- TM2: Transmit diversity
- TM3: Open-loop codebook-based precoding: Cyclic Delay Diversity (CDD)
- TM4: Closed-loop codebook-based spatial multiplexing
- TM5: Multi-user MIMO, two or four antennas (Ports 0, 1, or 0-3)
- TM6: Single-layer closed-loop codebook-based spatial multiplexing
- TM7: Non-codebook-based precoding for single layer (Port 5)
- TM8: Non-codebook-based precoding for up to two layers (dual layer Port 7-8, or single antenna port, Port 7 or 8)
- TM9 and TM10: Non-codebook-based precoding for up to eight layers (up to eight layers Port 7-14, or single antenna port, Port 7 or 8)

It is important to understand the behavior of these TMs under a variety of scenarios (such as propagation channel, number of transmit and receive antennas, and number of layers). This is normally achieved by means of link-level simulations, which measure the performance of the setup in terms of throughput. These curves are also used to study the performance of receiver algorithms.

LTE Toolbox provides functions and reference designs for link-level modeling. These can be easily modified to simulate different TMs, propagation conditions, and receiver algorithms. Modulation scheme, bandwidth, coding rate, resource allocations, duplexing scheme, and other system parameters are also accessible.

System Model

This application note considers all TMs except MU-MIMO. For the purpose of link-level simulations, TM9 and TM10 are considered to be the same.

Figure 1 shows the processing chain used in the simulations to calculate the results presented in this application note. It includes the following steps: waveform generation, propagation channel, and receive stages. The receiver blocks are also part of LTE Toolbox, which offers a set of baseline algorithms. The case considered here includes synchronization, channel estimation, and MMSE equalization. The PDSCH and DL-SCH decoding is performed to recover the transmitted bits and the HARQ indicator.

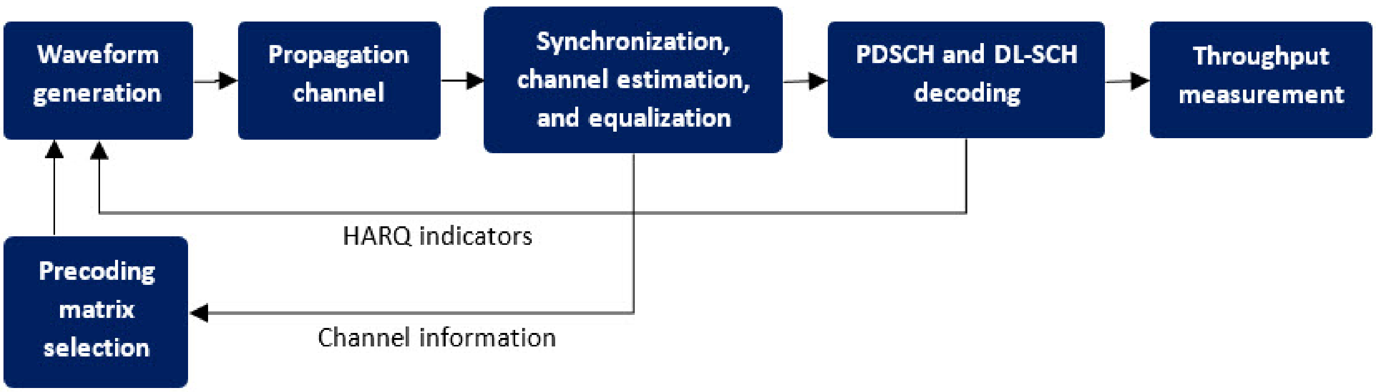


Figure 1. Processing chain for link-level simulation.

The precoding matrix selection is only applicable for TM4, TM6, TM7, TM8, TM9, and TM10.

The results shown are for a bandwidth of 50 resource blocks (RBs), where 10 RBs have been allocated. The modulation scheme and the coding rate used are 16QAM and 0.5, respectively. The channel used is EPA5. All these parameters are customizable, and their effect on throughput can be studied.

Results shown are throughput as a percentage of the total achievable amount for the given set of parameters (allocation, coding rate, etc.) and throughput in Mbps. The former is a measure of the robustness of the transmission, while the latter provides an indication of the capacity. All results have been obtained simulating 1,000 frames.

Throughput Results

Figure 2 compares the performance of TM1, TM2, TM3, TM4, and TM6 when using four receive antennas. As expected, TM2 (spatial diversity) is one of the most robust schemes, although it does not provide the highest capacity (throughput in Mbps). TM6 shows a similarly robust performance, proving that beamforming succeeds in maximizing the signal-to-noise ratio (SNR) at the receiver. The highest capacity is provided by TM3 and TM4 for high SNRs, which is expected, since they both use two layers—that is, two data streams in parallel. However, they require a higher SNR to attain a 70% throughput when compared with other TMs. TM3 and TM4 show similar performance for two transmit antennas. For larger numbers of antennas, TM4 outperforms TM3, since TM4 is based on channel knowledge, while TM3 is open loop.

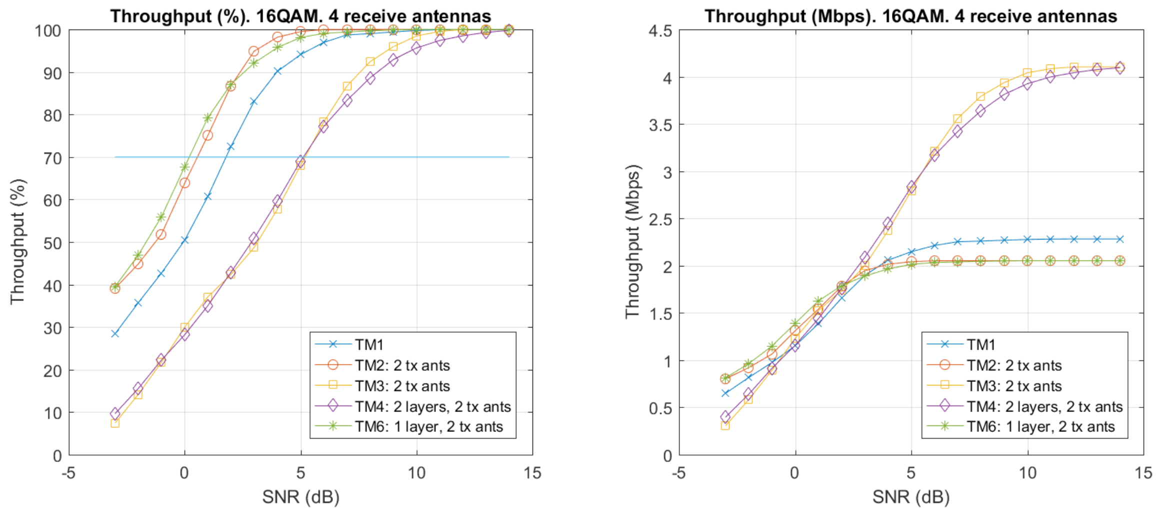


Figure 2. Throughput of TM1, TM2, TM3, TM4, and TM6 when using four receive antennas.

Figure 3 compares performance for TM1, TM7, TM8, and TM9. The best performance in terms of robustness (throughput %) is provided by TM7. This is expected since TM7 implements beamforming (one layer), which aims to maximize the SNR at the receiver. However, this comes at the cost of a lower overall capacity in Mbps when compared with other TMs. It is interesting to note that TM7 provides a lower capacity (throughput in Mbps) than TM1 for SNRs above 5dB. This kind of observation can help you choose between the available TMs.

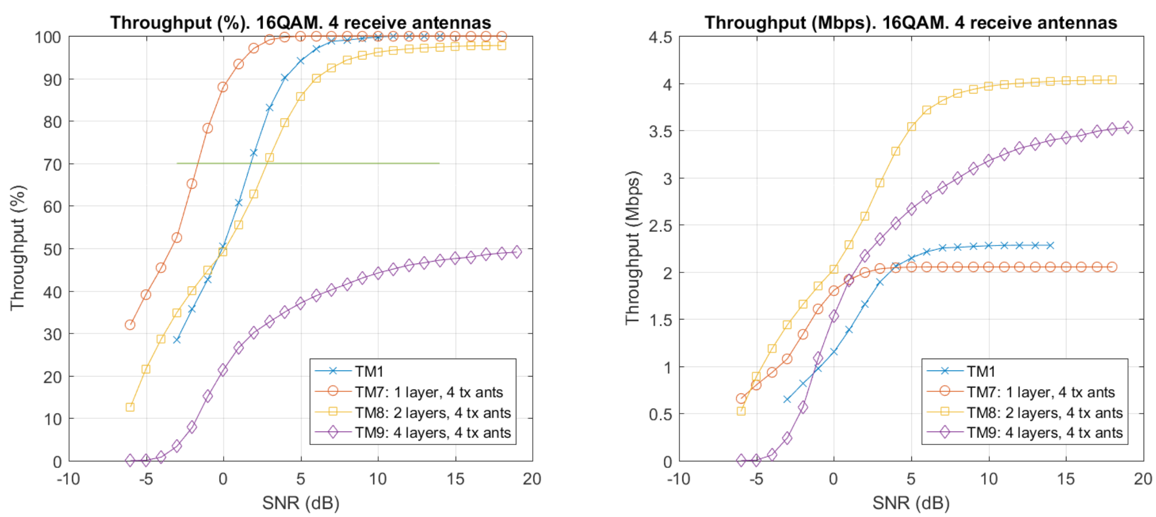


Figure 3. Throughput of TM1, TM7, TM8, and TM9 when using four receive antennas.

In Figure 3, the worst performance in terms of successfully received packets is provided by TM9. This is because in this example it uses four layers, and the 4x4 channel conditions are not capable of supporting them all. Figure 4 shows the performance of TM9 with four layers in 4x4 and 8x8 channel conditions. The 8x8 channel scenario has more degrees of freedom and supports four layers better than the 4x4 channel scenario.

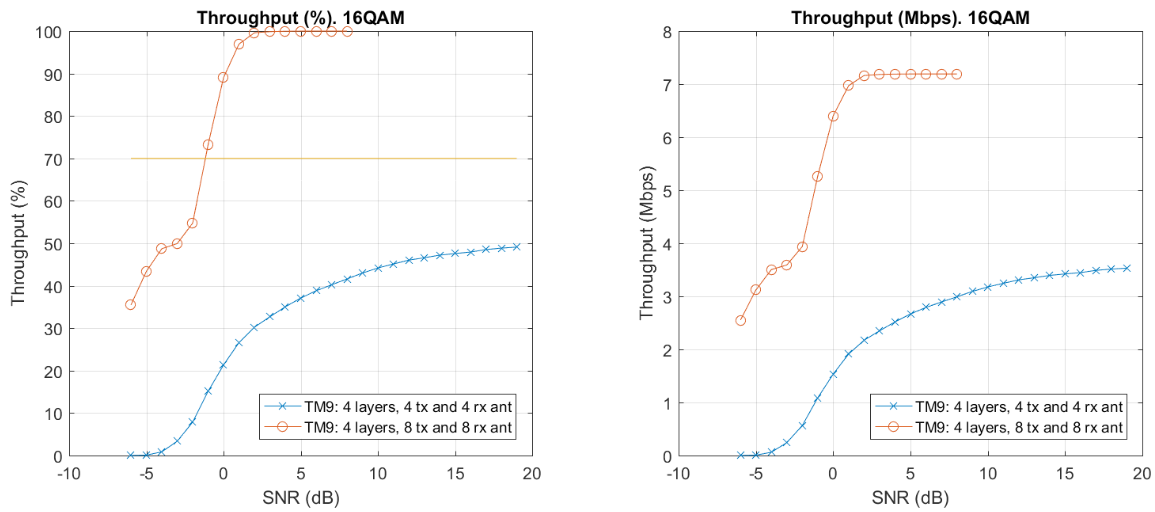


Figure 4. Throughput of TM9 with four layers when using 4x4 and 8x8 channels.

Another factor that has a noticeable effect in the performance of the system is the number of receive antennas. Figure 5 shows the effect of using a different number of receive antennas for TM1. For low SNRs, doubling the number of antennas provides a 3dB gain.

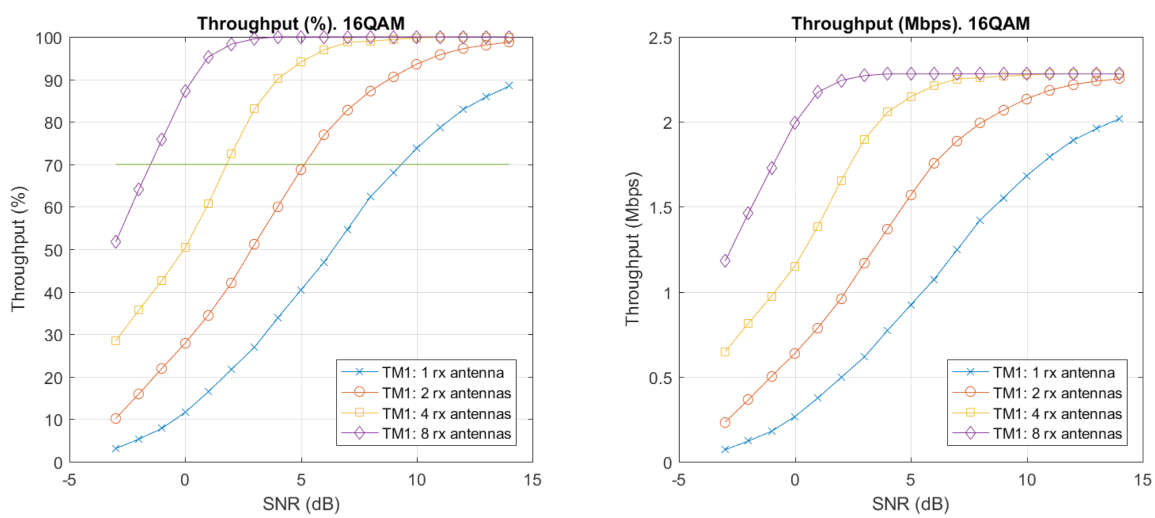


Figure 5. Throughput of TM1 with one, two, four, and eight receive antennas.

Finally, Figure 6 illustrates the differences between using a codebook approach (TM6) and a non-codebook approach (TM7) while keeping the rest of the parameters fixed (one layer, four transmit antennas, and four receive antennas). The limited choice of beamforming patterns provided by the codebook affects the performance.

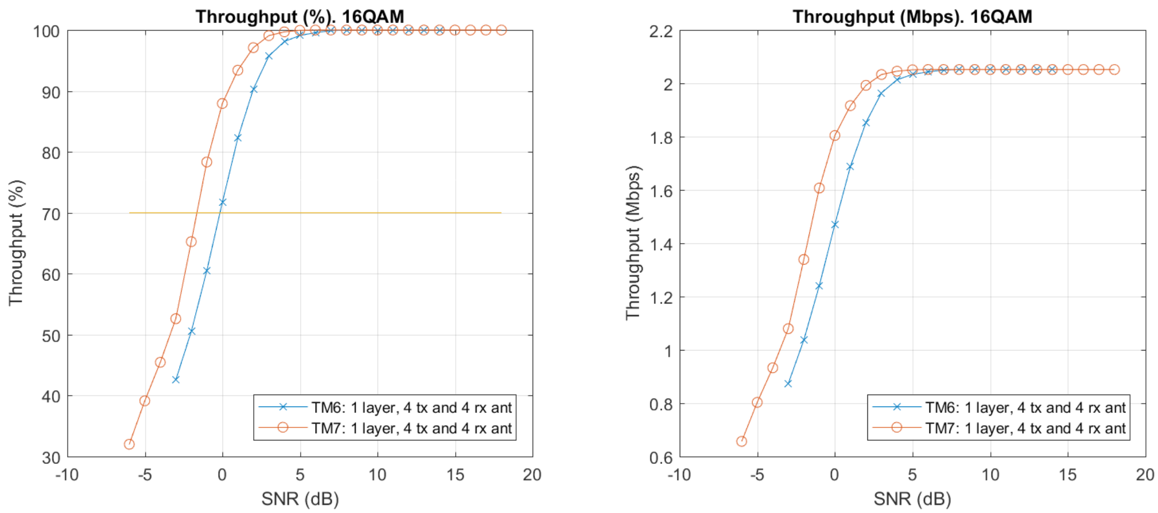


Figure 6. Throughput of TM6 and TM7 with one layer, four transmit antennas, and four receive antennas.

The results shown are for illustration purposes only. They are closely linked to the algorithms and parameters chosen in the simulations.

Parallel Computing

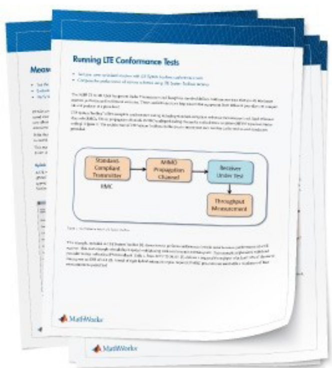
A large number of frames need to be simulated to obtain meaningful throughput curves. This results in long simulations. MathWorks offers parallel computing solutions you can use to speed up simulation time. *Parallel Computing Toolbox™* and *MATLAB Distributed Computer Server™* enable you to use different cores in your PC or computer clusters, respectively, to speed up simulation time. In the case of link-level simulations, different SNR points can be simulated in parallel, greatly reducing simulation time.

About LTE Toolbox

LTE Toolbox provides standard-compliant functions and apps for the design, simulation, and verification of LTE and LTE-Advanced communications systems. The system toolbox accelerates LTE algorithm and physical layer (PHY) development, supports golden reference verification and conformance testing, and enables test waveform generation. With the system toolbox, you can configure, simulate, measure, and analyze end-to-end communications links. You can also create and reuse a conformance test bench to verify that your designs, prototypes, and implementations comply with the LTE standard.

Learn More

LTE Tutorial: Understanding the LTE Resource Grid



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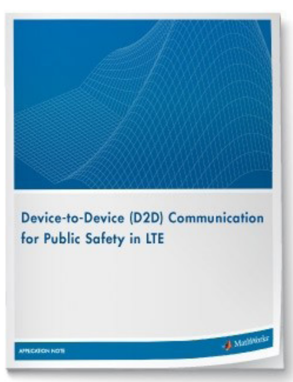

Application notes:
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