3GPP TSG RA WG1 Meeting RAN1-NR **R1-1700844**
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Source: Cohere Technologies

Title: Pilot Scrambling Sequences for DMRS Port Multiplexing

Agenda item: 5.1.2.3.2

Document for: Discussion and Decision

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1. Introduction

In RAN-87 there was agreement to study appropriate DMRS resource allocation patterns and multiplexing methods as indicated by the agreement text below:

> "Organize two email discussions i) to collect companies' proposals on DMRS design for DL data channel for NR to facilitate evaluation for the next RAN1 meetings till 12/9/16 and ii) to discussion/agree on simulation assumptions till 12/16/16 – Hyunsoo (LGE)
> - The companies are encouraged to provide DM-RS patterns including DM-RS design details such as
>   - Time domain density (per antenna port) for different ranks (e.g., number of DMRS symbols in slot, symbol position, etc.)
>   - Frequency domain density (per antenna port) for different ranks
>   - The number of maximum orthogonal ports
>   - Multiplexing of DMRS ports (e.g., TDM, FDM, CDM, etc.)
>   - DM-RS sequence (e.g., PN, Zadoff-Chu, etc.)"

In response to this agreement there has been a constructive email discussion with several DMRS patterns and multiplexing methods proposed by various companies. In general, a combination of FDM, TDM and CDM has been proposed, extending the approaches present in the design of LTE UE specific RSs. In terms of the actual pilot sequence employed for scrambling the transmitted pilot RE constellation values, generic PN or Zadoff Chu sequences have been mentioned, but little attention has been paid to the effect of the scrambling sequence to the separability of the pilot ports and the resulting channel estimation performance. In this contribution, we further investigate this connection, present some channel estimation performance results and propose some guiding principles in the choice of pilot sequences.

2. Pilot Sequences in LTE

Figure 1 shows the LTE pattern for UE specific RS (see [1]). The pilot ports are organized in two groups, each group separated by the other using FDM. Within one group, up to four pilot ports can be multiplexed using CDM. The multiplexing code is applied along time; no further multiplexing is performed along frequency. In fact, the pilot scrambling sequence is identical for all pilot ports (for SU-MIMO).

This LTE design was inspired by a low Doppler use case (closed loop MIMO) and low complexity implementation. Indeed, in the low Doppler case, the cover codes across time are received perfectly orthogonal, and simple projection to each cover code perfectly separates each pilot port, even in the extreme case of four pilot ports for a four-point cover code. Subsequently, channel interpolation via MMSE or other techniques can be performed on each pilot port separately.

However, under moderate Doppler effects, the orthogonality of the cover codes is compromised and the performance deteriorates as shown next.

3. Performance Under Doppler Spread

Some simulation results are presented in this section on channel estimation performance. The details of the simulation assumptions are given in a table in the appendix.

Figure 2 shows the channel estimation performance as a function of Doppler spread for the extreme case of multiplexing four pilot ports (namely ports 7,8, 11,12) on the four-point cover code. The channel power to channel estimation MS error ratio is shown, averaged over the whole TTI, versus max Doppler spread. The blue line indicates the performance using the LTE pilot sequence, which is identical for all pilot ports. Three SNR points are depicted, 25, 15 and 5 dB with solid blue, dashed blue and dash-dotted blue lines respectively. Notice that the performance deteriorates even for moderate Doppler, especially for the high SNR case; for example, for 100 Hz Doppler a loss of more than 15 dB is observed compared to 10 Hz Doppler.

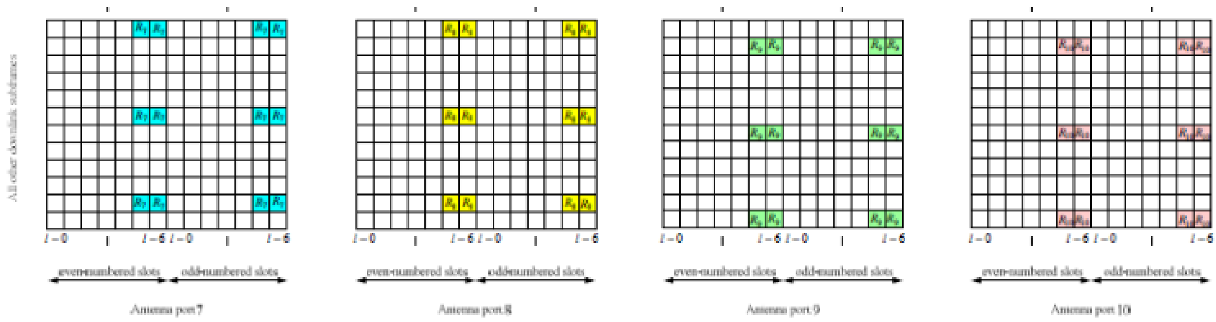

Figure 1: LTE UE Specific Reference Signal Pattern

The Doppler performance can be improved with a better design of the pilot sequences which exploits the potential of more advanced signal processing, i.e. joint pilot port MMSE interpolation. In that case the system benefits from pilot sequences that are not identical across pilot ports but afford some separability.

The red line in Figure 2 shows the performance when different pilot sequences are used for different antenna ports. The different sequences are generated by utilizing different initial conditions for the feedback shift register of the PN generator. Notice a remarkable improvement even for moderate mobility. For example, for 100 Hz Doppler, the performance improvement is more than 13 dB.

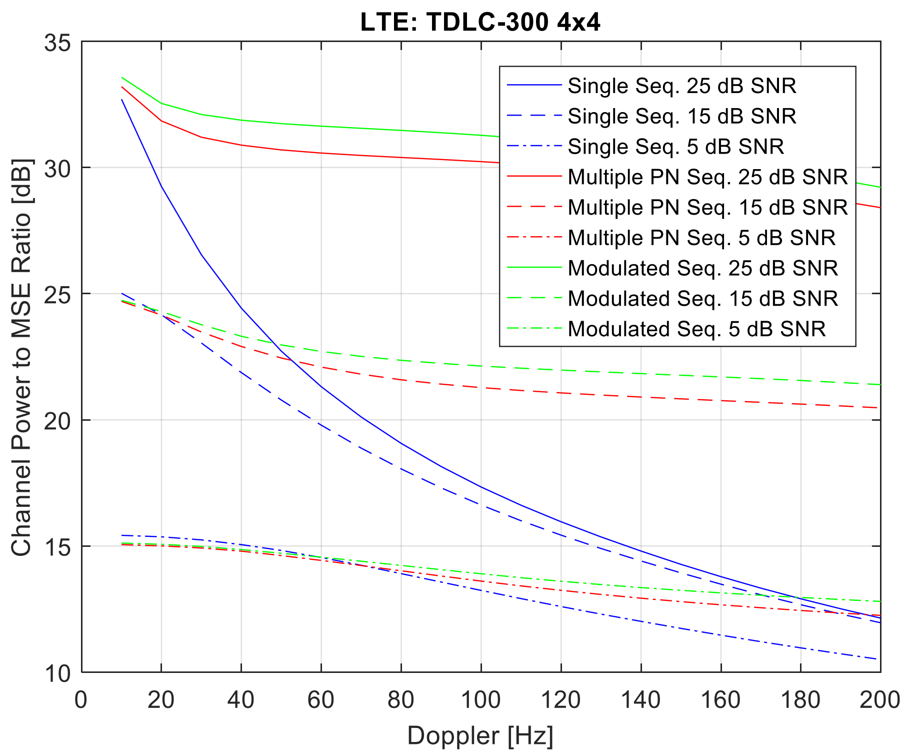

Figure 2: Channel Estimation Inverse NMSE vs Doppler for TDLC-300

A variation to the pilot sequence design provided above, is to use the same basic scrambling sequence for all ports but use a different circular shift of the pilot waveform (in the time domain) or linear phase modulation (in the frequency domain) for each pilot port. This approach has some relation to the pilots ideas discussed in [2]. For four ports we use a circular shift of 0, N/4, N/2 and 3N/4 samples respectively for each port where N is the OFDM symbol length. This is actually implemented by modulating the PN sequence in the frequency domain by complex exponentials of frequency 0, $\pi/2$, π, and $3\pi/4$ respectively. The performance is shown in Figure 2 in green line. The performance is similar and slightly better than the PN sequence randomization approach depicted in the red line.

Similar results are shown in Figure 3 for a channel with longer delay spread (TDLC-1000). The robustness to Doppler is reduced in this more challenging channel for all cases, but significant improvement is still evident.

The following observations are now in order:

Observation 1: Performance of cover code multiplexing deteriorates with mobility, when the maximum number of pilot ports possible are multiplexed.

Observation 2: Assigning different pilot sequences to different pilot ports can significantly improve performance in moderate to high Doppler.

Observation 3: Differentiating the pilot sequence for each port can be achieved by

- **Different initial conditions for the PN generator or**
- **Cyclic shifts of the same pilot sequence**

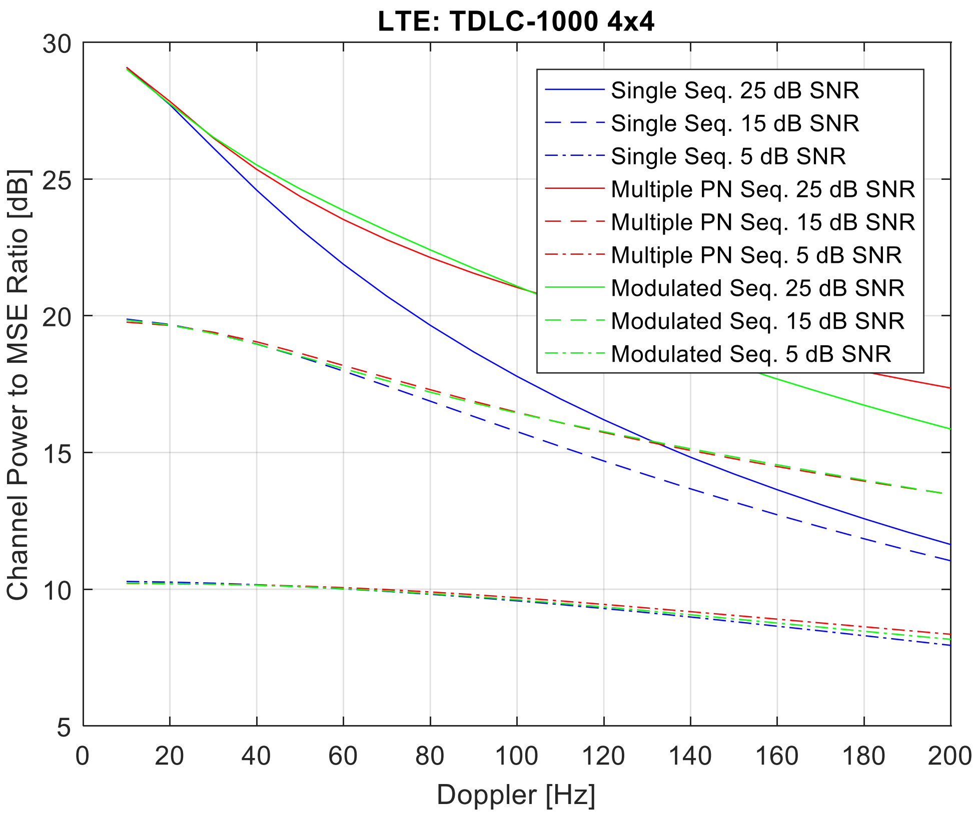

Figure 3: Channel Estimation Inverse NMSE vs Doppler for TDLC-1000

4. Pilot Sequences For NR

In this section we study the different pilot sequence options above to DMRS patterns that may be more suitable for NR. The discussion on the appropriate DMRS patterns for NR is still ongoing and a large number of proposals have been put forward from different companies. Discussing the commonalities and merits of those proposals is outside the scope of this contribution, but we still want to study the effect of pilot sequence choice on a pattern that would include the essence of multiple proposals. The pattern shown in Figure 4 (proposed by ZTE) is the pattern we chose and contains the following characteristics found in many other proposals as well.

- Pilots are arranged in the frequency domain along a symbol at the beginning of the subframe and an OCC-2 is used to multiplex two antenna ports.
- In the case of mobility, a second symbol with pilots is placed in the middle of the subframe
- OCC-2 (along frequency) or COO-4 (along time and frequency) codes are used when we need to multiplex two or four ports respectively.

In this section we study the extreme case of multiplexing four ports on an OCC-4 code spanning four time and frequency points of the pilot grid of Figure 4.. Similar to LTE, one value of the pilot scrambling sequence is applied to (multiplies) each 4-point OCC code for each pilot port.

Figure 5 shows the results for the TDLC-300 channel, which appear similar to those for the LTE pilots of Figure 2. We see similar significant gains for both the random initialization pilot sequence case and the circularly shifted pilot sequence case. These gains are maintained for longer delay spread channels. Figure 6 shows the performance results for TDLC-1000 with performance gains comparable to those in Figure 3.

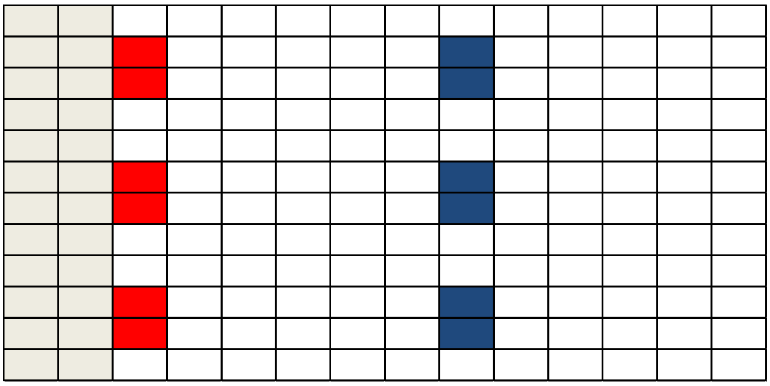

Figure 4: Time-frequency reference signal grid example.

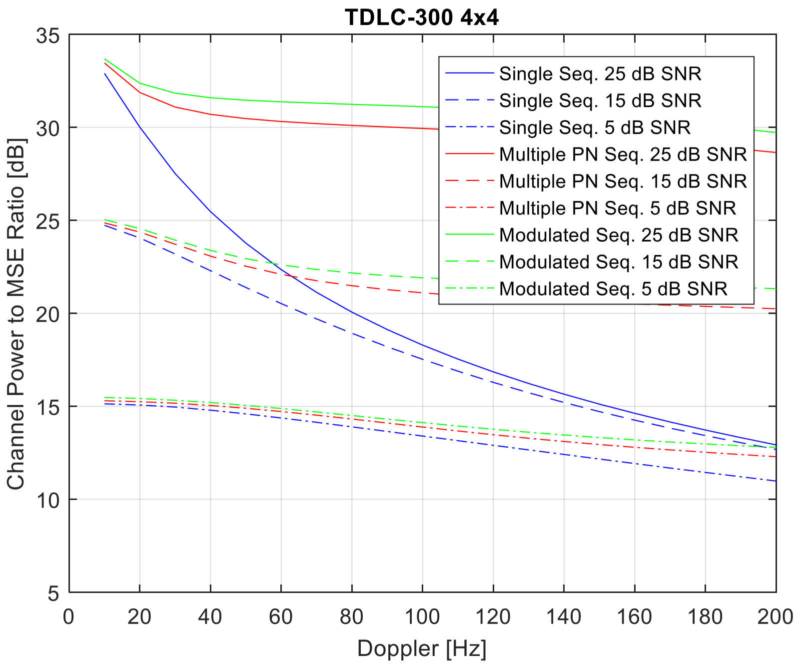

Figure 5: Channel Estimation Inverse NMSE vs Doppler for TDLC-300, Pilot Grid of Figure 4

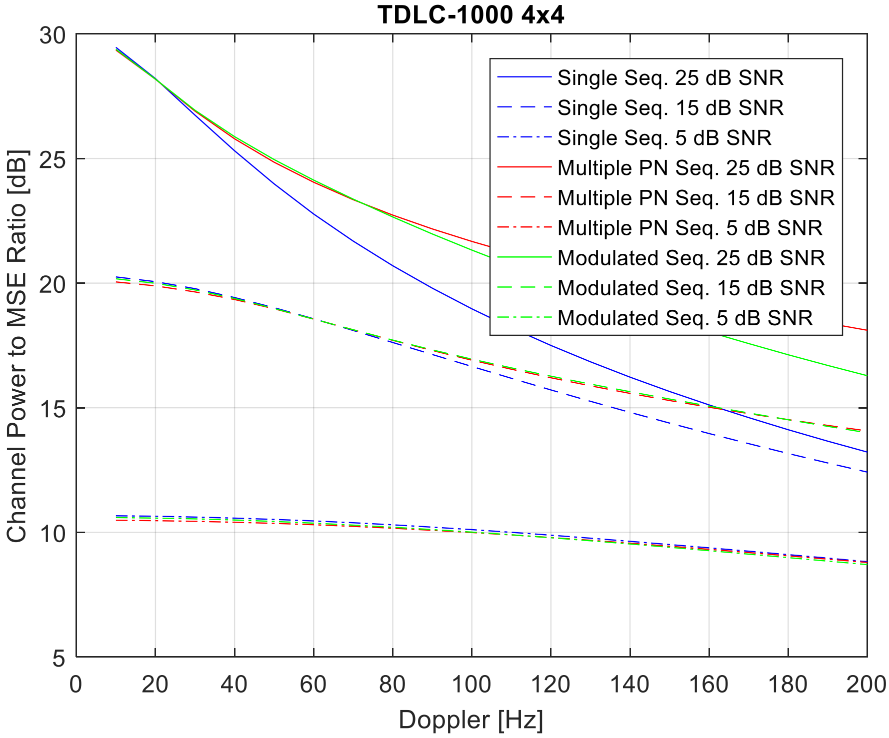

Figure 6: Channel Estimation Inverse NMSE vs Doppler for TDLC-1000, Pilot Grid of Figure 4

Our final test case involves small PRB allocations. All previous results correspond to a full bandwidth transmission (in this case 10 MHz). In Figure 7, we present results similar to Figure 2 but for in allocation of 4 PRBs with the same LTE DMRS pattern.

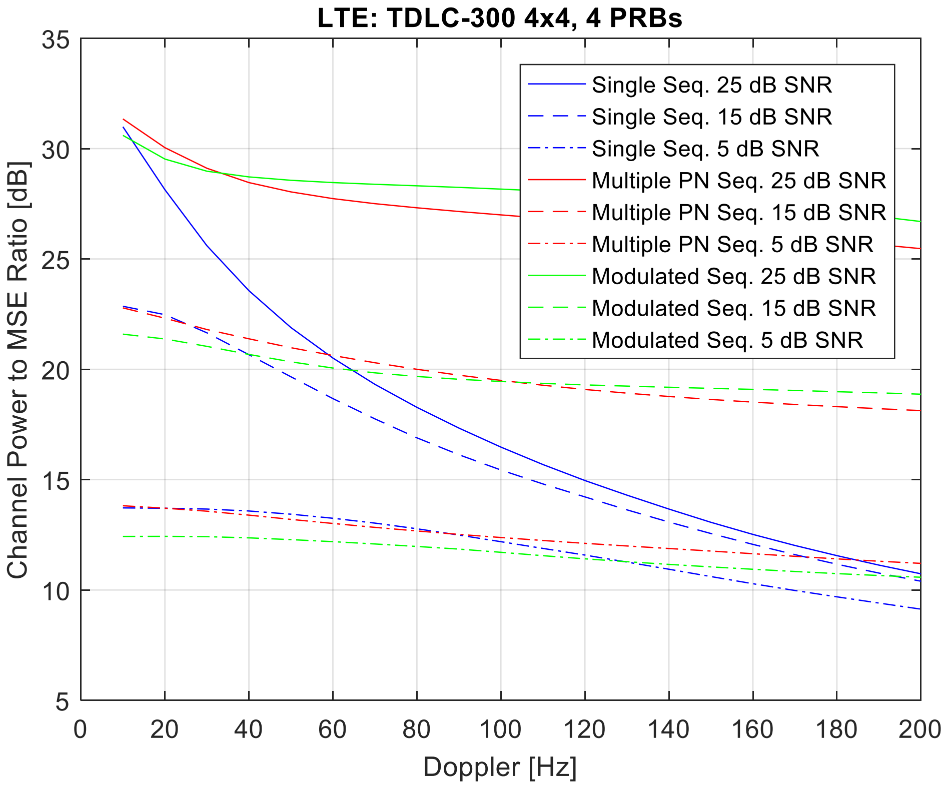

Figure 7: Channel Estimation Inverse NMSE vs Doppler for TDLC-300

Notice that the results are only slightly worse than Figure 2, while the performance improvement between port independent and port dependent pilot sequences remains impressive.

Finally, in Figure 8 we repeat the small allocation (4 PRBs) experiment but with the NR DMRS pattern of Figure 4. We see significant performance improvement for this DMRS pattern as well.

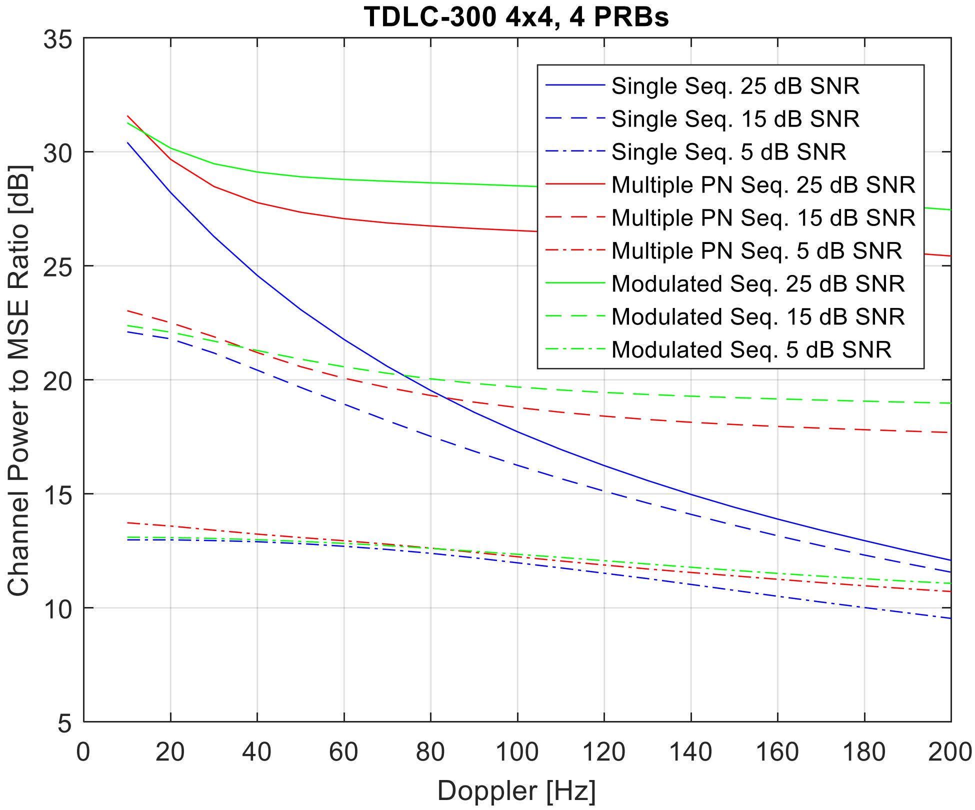

Figure 8: Channel Estimation Inverse NMSE vs Doppler for TDLC-300

The above results indicate that the performance gains are not tightly coupled to the choice of pilot pattern grid and will likely hold for a large number of the proposed patterns. While it is true that those gains materialize with joint MMSE pilot estimation, it would be wise to choose pilot sequences in NR that do not preclude the gain potential of this advanced signal processing technology.

Proposal 1: Pilot sequences should not be identical for all ports multiplexed with an OCC code. Different sequences can be generated by

- **Circularly shifting a base pilot sequence or**
- **Changing the initial state of the PN sequence generator**

5. Conclusion

In this contribution we have shown the benefits of using different pilot sequences for different antenna ports. Based on these benefits we have the following observations and proposal

Observation 1: Performance of cover code multiplexing deteriorates with mobility, when the maximum number of pilot ports possible are multiplexed.

Observation 2: Assigning different pilot sequences to different pilot ports can significantly improve performance in moderate to high Doppler.

Observation 3: Differentiating the pilot sequence for each port can be achieved by

- **Different initial conditions for the PN generator or**
- **Cyclic shifts of the same pilot sequence**

Proposal 1: Pilot sequences should be different for different ports multiplexed with an OCC code. Different sequences can be generated by

- **Circularly shifting a base pilot sequence or**
- **Changing the initial state of the PN sequence generator**

6. References

[1] 3GPP TS 36.211, Physical channels and modulation, Rel 12.

[2] R1-163619, "OTFS Modulation Waveform and Reference Signals for New RAT," Cohere Technologies, AT&T, CMCC, Deutsche Telekom, Telefonica, Telstra, TSG RAN WG1 #84b, Busan, South Korea, April 2016.

7. Appendix

Table 1: Simulation Parameters

Parameter	Value
Carrier frequency	4 GHz
System BW	10 MHz
TTI length	1 msec
Subcarrier spacing	15 KHz
FFT size	1024
CP length	4.7 usec
Channel estimation	Joint pilot MMSE Estimation
Channel profile	TDLC-300, TDLC-1000
Doppler Spread	0-200 Hz
Pilot pattern	LTE Port 7,8,11,12 – NR example
MIMO correlation	Low
Pilot sequence	PN sequence, modulated PN sequence