

# Performance Evaluation of LTE-V Sidelink in Fading Channel of Various Doppler Spread

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## Abstract

The 3<sup>rd</sup> Generation Partnership Project (3GPP) Release 12 standards introduced sidelink (SL) channels for direct communication between multiple user equipments (UEs) without being mediated by an eNodeB in Long Term Evolution (LTE). This service was enhanced in 3GPP Release 14 using SLs for vehicle-to-everything (V2X) communication, referred to as LTE-Vehicular (LTE-V) services. As a new technology, its performance needs to be estimated under various channel conditions prior to practical deployment, in order to help tune parameters appropriately for radio network planning. In this paper, a quantitative analysis of the performance of LTE-V SLs is performed using MATLAB based simulation for various Doppler spread in the fading channel. The simulation demonstrates performance using throughput and block error rate (BLER) as the descriptors for different signal to noise ratio (SNR) levels. The performance was also checked for different number of MIMO receiving antennas. An analysis of the simulation results is presented, which highlights the impact of different parameters.

## Key words:

*Vehicle-to-Everything (V2X) communication, LTE-V, Sidelink, Doppler spread*

## 1. Introduction

Cellular networks have been used almost universally to provide mobile services to millions of users worldwide. In the last several decades, communication between UEs has relied exclusively on the base station (BS). While this architecture allows for strong mobility management, it comes at the cost of spectral utilization, energy consumption, and transmission latency. These inefficiencies are especially pronounced when UEs are in close proximity to one another, so much so that UEs would stand to benefit from direct communication [1]. In LTE platform, to circumvent the base station (BS), known as eNodeB, sidelink (SL) channels were introduced in 3GPP Release 12 [2]. Vehicular applications are latency and energy sensitive and as such do not work well with eNodeBs [3], [4]. Aiming to provide safer, faster and more efficient transportation, 3GPP Release 14 introduced support for vehicle-to-everything (V2X) communication using LTE-V SL operation [5]. These services have not yet been deployed but a massive deployment is expected to occur before long.

The standards of V2X communication have been developing very fast. As a new but promising technology, LTE-V SL merits thorough performance analysis. This is primarily because the performance analysis, prior to the deployment of LTE-V SL, can help in proper settings of the relevant radio parameters. Limited performance analyses have been published so far. Liu et al conducted a performance measurement of a V2X communication system for vehicle and pedestrian safety [6]. Arslan et al conducted a survey to study the effects of OFDM design parameters for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication [7]. Yu et al evaluated the performance of LTE-V based vehicle-to-vehicle platooning communication [8]. This paper performs a quantitative analysis of the performance of LTE-V SL using MATLAB based simulations. To check the performance, the propagation environment was taken in different conditions, by varying the Doppler frequency. Also, the receiving side set up was taken in different conditions, by varying its number of MIMO antennas. The error rate and throughput, two major key performance indicators (KPIs), were used to numerically assess the impact on performance while varying Doppler frequency and the number of receiving antennas.

The remainder of the paper is outlined as follows. Section 2 discusses how vehicular support has been gradually added to LTE using SL communication. Section 3 explains the impact of Doppler spread. Section 4 explains the simulation procedure and analyzes the results. Finally, the whole paper is concluded in section 5.

## 2. Evolution of LTE-V

LTE was introduced as a cellular communication standard by 3GPP in Release 8 of its document series. Being ten times as fast as 3G, it made a huge impression. Simplification of system architecture, scalable bandwidth (1.25-20 MHz), low latency in handover as well as data transfer, usage of Orthogonal Frequency Division Multiple Access (OFDMA) technique in downlink and Single Carrier FDMA (SC-FDMA) in uplink for power conservation, Input Multiple Output (MIMO) techniques for exploiting multipath propagation, and so forth, made

LTE a strong contender in the telecommunication industry. In Release 10, LTE-Advanced (LTE-A) was introduced with major enhancements in the form of faster throughput. An example of the new features in this release is carrier aggregation (CA) that leads to a maximum carrier bandwidth of 100 MHz. Following this improvement, LTE-Advanced Pro (LTE-A Pro) was introduced, in Release 13 and 14, with the aggregation of 32 carriers, a massive 640 MHz bandwidth. It allows both licensed and unlicensed spectrums and 16 antenna paths in a single radio cell which can go up to 64. LTE-A Pro offers lower latency, smoother data rate experience for the user, and higher cell capacity compared to LTE-A [5].

### 2.1 3GPP Release 12 Sidelink

The salient feature of the traditional LTE architecture is that the resource allocation and mediation of subsequent communication are performed through an eNodeB [9]. The eNodeB communicates with UEs over uplink and downlink for signaling as well as data. It stands to reason that communication between UEs via a base station would involve more latency than direct communication with each other [1], [10]. 3GPP Release 12 introduced the device-to-device communication (D2D) for public safety usage. Several new interfaces were introduced in this release, of which PC5 and PC3 are of most interest. PC3 interfaces a UE with an unknown node while PC5 is a one-to-many interface specified for group communications [11]. Two logical channels are defined for SL communication, SL Traffic Channel (STCH) and SL Broadcast Control Channel (SBCCH).

The STCH is a point-to-multipoint channel carrying user information from proximity service (ProSe) applications. The STCH is connected to SL Shared Channel (SL-SCH) which interfaces to the Physical SL Shared Channel (PSSCH). The PSSCH transports data over the air but bears a collision risk depending on resource allocation by eNodeB. The SBCCH is used for synchronization purposes and carries signaling information. The uniform sized blocks from the SBCCH enable it to be connected with the SL Broadcast Channel (SL-BCH), which is a transport channel with a predefined format. The SL-BCH interfaces with the Physical SL Broadcast Channel (PSBCH). The Physical SL Control Channel (PSCCH), sent prior to the STCH data block, is equivalent to Physical Downlink Control Channel (PDCCH) of early specifications. The PSCCH carries the Sidelink Control Information (SCI). The receiving UE uses the information contained in the SCI to receive and demodulate the PSSCH [12].

### 2.2 3GPP Release 14 Sidelink

LTE-Vehicular (LTE-V), introduced in 3GPP Release 14, added vehicular services. Depending on their type, the LTE-V2X (Vehicle to Everything) services can be classified into

non-safety, safety and automated driving services. Non-safety related messages ensure comfortable transportation by providing pertinent information about the optimum speed that maximizes fuel economy through intermittent acceleration and reduces the travel time through efficient traffic management. These messages are delay tolerant. Safety related messages are intended to reduce, if not eliminate, accidents by warning the driver beforehand. These messages are time sensitive and any delay may lead to a dire outcome [10]. Automated driving services, while still under development, are also time sensitive. These factors necessitate unmediated communication between UEs.

The modes of operation, offered by V2X, include vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and vehicle-to-pedestrian (V2P) [13]. These forms of direct communication can be performed without necessarily relying on the eNodeB for scheduling and allocation. The Release 14 SL, used for LTE-V, has a number of distinguishing features over the Release 12 SL. The Release 14 SL has lower latency and higher reliability requirements. It is subject to larger Doppler shifts due to higher relative speeds. There are a large number of nodes, leading to high node densities, which present challenges to synchronization in out-of-coverage scenarios. As a new but complicated technology, Release 14 SL merits an investigation of how its key performance indicators (KPIs) are affected when relevant parameters vary.

### 2.3 3GPP Release 15 and Beyond

The first phase of 5G technologies, expected to be completed by April 2019, is being outlined in 3GPP Release 15. Release 16 is expected to complete the second phase by April 2020 and it is submitted to the International Telecommunication Union (ITU) as a candidate of IMT-2020 Technology. ITU has divided 5G services into enhanced mobile broadband (eMBB), ultra-reliable low-latency communications (URLLC) and massive machine type communications (MMTC). Among them, URLLC includes industrial applications and autonomous vehicles. The 5G Automotive Association has been working on Cellular V2X (C-V2X) technology based on 5G New Radio (NR) for V2V and V2I applications [14].

## 3. Impact of Doppler Spread

In the multipath environment, the user velocity causes the Doppler shift that changes the frequencies of almost all multipath components. This is referred to as frequency dispersion. The frequency responses of different multipath components are affected differently. Thus, the resultant frequency response signifies signal distortion. The extent of overall frequency response increases and it increases more as Doppler shift increases. The increase in overall frequency

response is referred to as Doppler spread. The maximum Doppler shift can be shown equal to a ratio of user velocity and wavelength. The Doppler spread is often estimated as a deviation of the frequency response equal to twice as much as the maximum Doppler shift. The frequency dispersion characteristics of the multipath channel are related to time-variation of the multipath channel. The coherence time is an estimate of the range of time over which the impulse response of the multipath channel does not vary significantly. The comparison between the Doppler spread and the signal bandwidth is related to the comparison between the coherence time of the multipath channel and the symbol period of the transmitted signal. The transmitted signal is subject to slow fading when the channel impulse response varies slowly as compared to the variation in the transmitted signal. On the other hand, the transmitted signal is subject to fast fading when the channel impulse response varies quickly, within the symbol period, causing significant distortion. Equivalently, in the frequency domain, the Doppler spread is large compared to the signal bandwidth in case of fast fading. This signifies that the frequency response of the transmitted signal has been significantly spoiled causing significant distortion. In general, the coherence time is inversely proportional to Doppler spread [15], [16].

The inherent robustness of LTE-V helps overcome the distortion from Doppler shift. This includes frequency domain equalization, coding techniques, interleaving, multiple input multiple output (MIMO) antenna techniques, and so forth. Nevertheless, the user may experience poorer data rate and higher number of erroneous packets as the Doppler shift increases. The use of higher number of antennas for MIMO can help mitigate the signal distortion and improve the performance.

#### 4. Simulation and Result Analysis

In order to investigate the impact of various parameters on the KPIs of LTE-V SL, MATLAB based simulations were used using parameters shown in Table 1. For this purpose, the KPIs are selected as throughput and block error rate (BLER). The Doppler spread was varied in the simulated environment. The effect was checked for different number of receiving MIMO antennas. The throughput and BLER of PSCCH were derived for a range of SNR values. In the simulation, the OFDM modulated resource elements (REs) of a resource block (RB) were assigned to PSCCH and PSSCH. Additive white Gaussian noise (AWGN) was applied to the baseband signal to create a noisy fading channel. A simulation was performed subframe by subframe for a number of specific SNR values. The Doppler frequency and the number of receiving antennas were varied in the simulation. For each set of parameters, BLER and throughput were plotted against SNR. High throughput

and low BLER are indicative of good performance and vice versa.

Table 1: Simulation Parameters

No. of radio frames	500 (5 seconds)
SNR Range	-15 to +15 dB
Transmission Time Interval	8 subframes
Subframe Gap	4 subframes
Channel Delay Profile	EVA
Doppler Frequency	500, 1000, 1500, 2000, 2500, 3000 Hz
Number of Receiving Antennas	1, 2, 4
Modulation Scheme	QPSK

The simulation results are shown in Figures 1 – 12. In general, the simulation yielded, as expected, better performance as the Doppler frequency decreases, and the numbers of receiving antennas increases. An overall analysis of the simulation results, as shown in the figures, can be summarized as follows.

- BLER decreases, as shown in Figures 1, 2, 5, 6, 9 and 10, and throughput increases, as shown in Figures 3, 4, 7, 8, 11 and 12 as the Doppler frequency decreases, and the number of receiving antennas is increased. The performance also improves as SNR increases.
- Figures 1 and 2 show that a higher number of receiving antennas can yield significantly lower BLER if other variables are kept identical. When using one receiving antenna, at the highest SNR value, the largest improvement in BLER (42% to 9%) is observed between Doppler frequency values of 500 and 1000 Hz. Subsequent improvements are far less pronounced.
- Figures 3 and 4 show that a higher number of receiving antennas can yield significantly higher throughput if other variables are kept identical. At Doppler frequency of 3000 Hz, there is negligibly small throughput at any SNR when one receiving antenna is used. This value rises to 70% at 15 dB SNR when four receiving antennas are used. In the case of high Doppler frequency of 3000 Hz, even with four receiving antennas, the throughput did not exceed 70% up to 15 dB SNR.
- Figures 5 and 6 show that BLER decreases as SNR and the number of receiving antennas increase. An increase in Doppler frequency from 1000 Hz to 2000 Hz, causes BLER to degrade significantly.
- Figures 7 and 8 show that throughput increases as SNR and the number of receiving antennas increase. An increase in Doppler frequency from 1000 Hz to 2000 Hz, causes throughput to improve significantly. At 2000 Hz Doppler frequency, the throughput failed to rise to 100% at 15 dB only when one receiving antenna is used.
- Figures 9 and 10 show that BLER decreases as

Doppler frequency decreases and the number of receiving antennas increases. An increase in SNR from -5 dB to 5 dB causes BLER to improve substantially. At 5 dB SNR, BLER is negligibly small at any Doppler frequency when four receiving antennas are used.

- Figures 11 and 12 show that throughput increases as Doppler frequency decreases and the number of receiving antennas increases. An increase in SNR from -5 dB to 5 dB causes throughput to improve substantially. The throughput falls to negligibly small value at -5 dB SNR, for all values of Doppler frequencies, when one receiving antenna is used. On the other hand, the throughput rises to over 90%, at 5 dB SNR, when the Doppler frequency becomes as low as 1000 Hz.

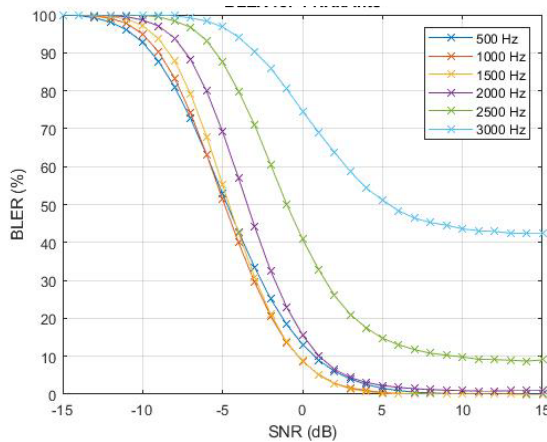


Fig. 1 Block Error Rate vs. SNR at varying levels of Doppler Frequency for 1 Receiving Antenna

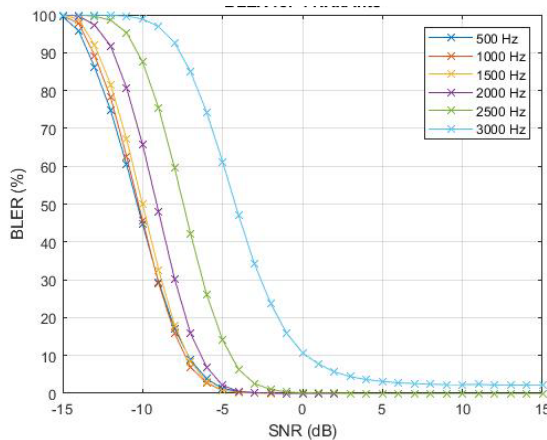


Fig. 1 Block Error Rate vs. SNR at varying levels of Doppler Frequency for 4 Receiving Antennas

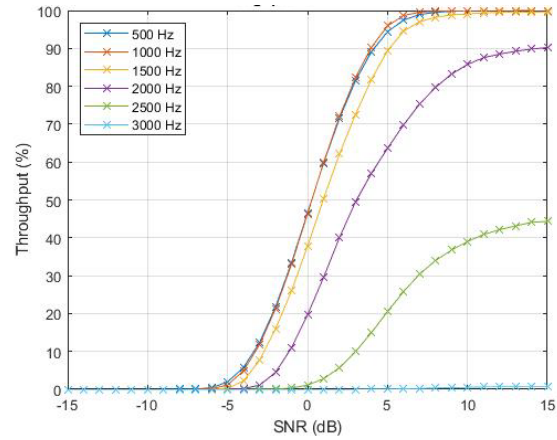


Fig. 2 Throughput vs. SNR at varying levels of Doppler Frequency for 1 Receiving Antenna

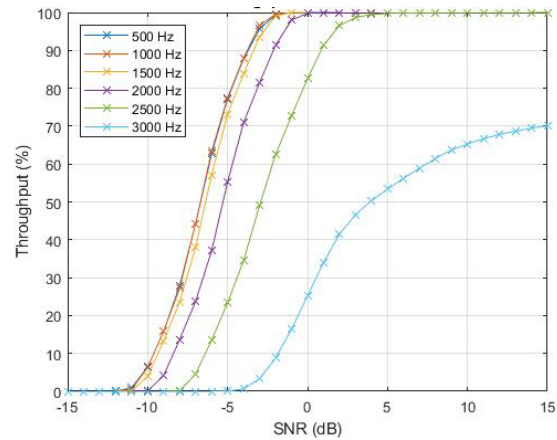


Fig. 3 Throughput vs. SNR at varying levels of Doppler Frequency for 4 Receiving Antennas

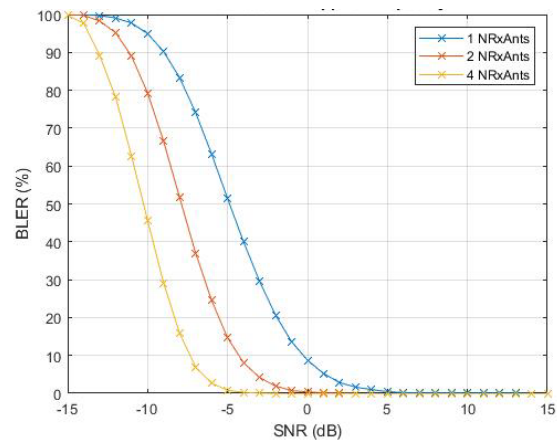


Fig. 4 BLER vs. SNR for different numbers of Receiving Antennas at 1000Hz Doppler Frequency

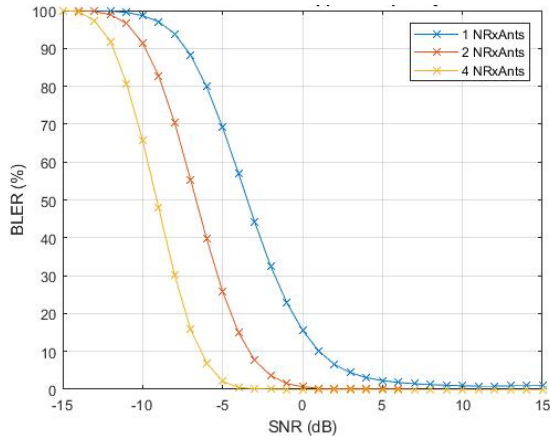


Fig. 5 BLER vs. SNR for different numbers of Receiving Antennas at 2000Hz Doppler Frequency

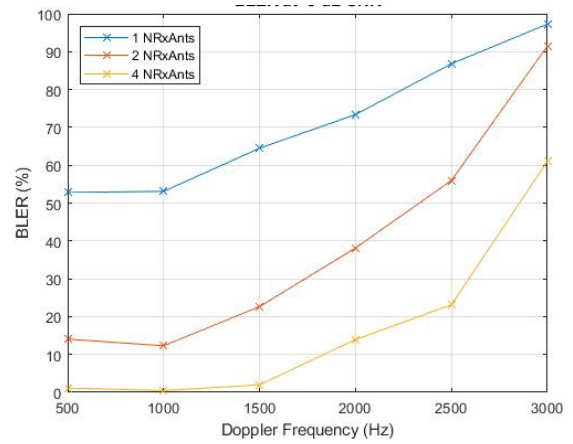


Fig. 8 BLER vs. Doppler Frequency for different numbers of Receiving Antennas at -5 dB SNR

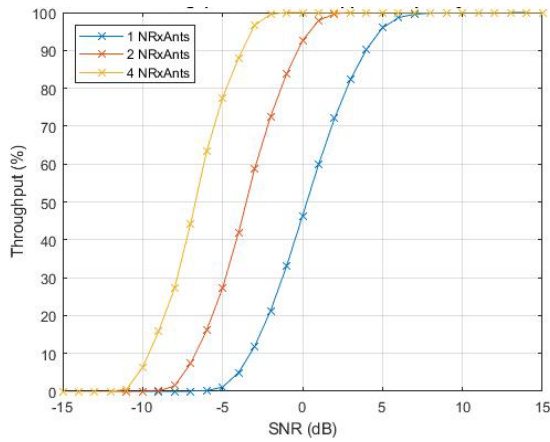


Fig. 6 Throughput vs. SNR for different numbers of Receiving Antennas at 1000Hz Doppler Frequency

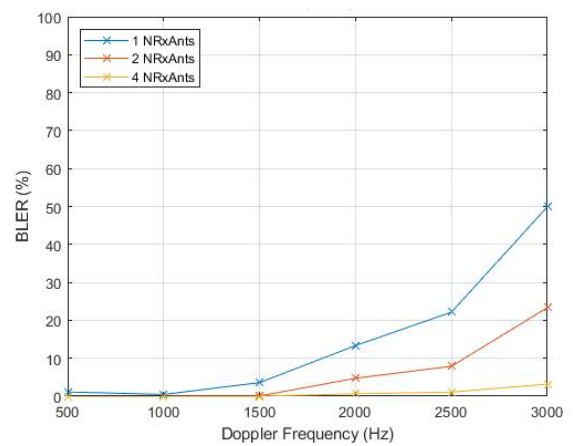


Fig. 9 BLER vs. Doppler Frequency for different numbers of Receiving Antennas at +5 dB SNR

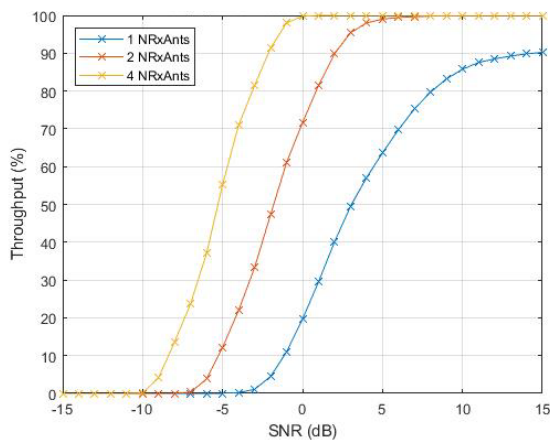


Fig. 7 Throughput vs. SNR for different numbers of Receiving Antennas at 2000Hz Doppler Frequency

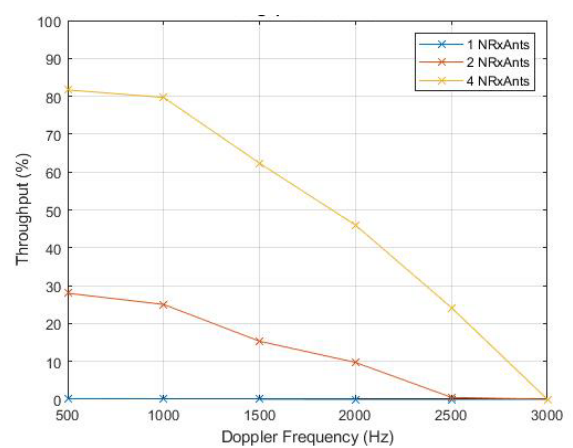


Fig. 10 Throughput vs. Doppler Frequency for different numbers of Receiving Antennas at -5 dB SNR

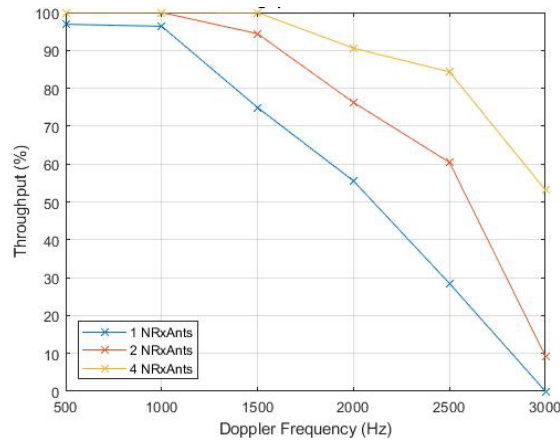


Fig. 11 Throughput vs. Doppler Frequency for different numbers of Receiving Antennas at +5 dB SNR

## 5. Conclusion

The standards of V2X communication have been developing very fast. It is important, for this new technology, to have a proper estimation of dependency among various radio parameters prior to its deployment. In this paper, the performance of LTE-V SL channels has been analyzed in terms of throughput and BLER. A variation in the dynamic characteristics of the channel has been made in the analysis, which is reasonable in the context of V2X scenario. In addition, different number of MIMO receiving antennas were used to determine its effect. Although the basic dependency of throughput and BLER on Doppler spread and the number of receiving antennas could be predicted for various SNR, the MATLAB based simulations have yielded results demonstrating the various relationships quantitatively. This quantitative determination can help in optimized radio network planning.

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