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Coverage enhancements of vehicles users using mobile stations at 5G cellular networks

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ABSTRACT

High mobility requirements are one of the challenges face fifth-generation wireless (5G) cellular networks by providing acceptable wireless services to users traveling at speed up to 350 km/h. This paper presents a new scenario to increase the bit rate and coverage for passengers that use the vehicles for traveling through the installation a mobile station (MS) on these vehicles to provide a high-quality service to users. Based on signal to noise ratio (SNR's) mathematical derivation and the outage probability of the user link, the proposed system is evaluated. Numerical results indicate an enhancement for users who received signal strength (RSS) from (-72 to -55) dBm and (15 to 38) Mbps in bit rate. Moreover, their number of users increased by proposed system adoption.

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1. INTRODUCTION

With the growing number of smartphones users inside vehicles, the need to improve wireless services has emerged. Fifth-generation wireless (5G) is the latest iteration of cellular networks. It engineered to greatly increase the speed and coverage for the usres [1], [2]. Many people prefer to use road transport such as vehicles, the metro, and trains in traveling. This type takes a long time to reach the intended destination; in addition to that, the passengers complain of the interruption in wireless services with the speed of vehicles [1], [3]. On the other hand, the 5G communications required providing high-speed data rate, high capacity with an increasing number of users and a short time in the handover process, hence the urgent need to use mobile relays to solve all these problems.

Several works in the literature studied the potential of extending cell coverage through mobile station use [3]-[5]. Most of these works focused on serving indoor users, and proposed ways to determine the MS placements and supporting mechanisms, like handover and association [6], [7]. The research focused on the alternative adoption of vehicle-to-vehicle (V2V) and vehicle-to-roadside (V2R) communications that travel for the short range where authors have presented a simple routing algorithm for timely data [8], [9]. Shah *et al*. [10] discussed the concept of moving-personal-cell (mPC) to provide network services for moving users. This scheme used mPC also to increase the network capacity, and addresses the effect of cross-tier and co-tier interference on the mPC also the data traffic impact through the backhaul and direct links is studeid in this scheme. In order to get more benefits in terms of throughput and signal to interference and noise ratio (SINR) the authors in [11], proposed association framework to relay distribution where they use mobile relays to achieve a significant gain for public transportation vehicles. Assegie *et al.* [12] explored a models employed for mobile stations for improving its performance within software. Different modeling techniques are used to achieving the high capacity for all users in dense erea for 5G Networks, one of these techniques is using mobile stations as studied in [13]. Although, the most related works discussed using the mobile station to enhance the received signal, they did not address the performance evaluation using the outage probability parameter [14]. The central contribution of this paper is proposing a new scenario to increase the bit rate and coverage for the passengers that use the vehicles based on install mobile staion (MS) on these vehicles to provide a high-quality service for user's mathematical analysis besides simulation are introduced in this paper. There are two types of an antenna connected with MS, an outdoor antenna will receive the cell signal from the base station evolved universal terrestrial radio access network (E-UTRAN Node B) eNB, then the MS will amplify this signal, the vehicle users will receive stronger cell signal from the indoor omni-directional antenna where the indoor antenna can provide 360° signal coverage

MS based on the received signal from the nearest eNB and resend it after amplification. There are two types of MS: the first is amplify and forward (AF) station, it is low cost and easy in configuration. The second is namely decode-and-forward (DF), which is encodes the signal before retransmission to its destination [15]. DF removes the noise that accompanies the original signal therefore, it is more complicated than AF [14], [16].

2. PROPOSED MODEL

As depicted in Figure 1, we proposed the first tier of eNB deployed where the user inside the vehicle received the signal via two links, direct link (DL) directly from eNB while the second signal by the mobile station MS link as shown in Figure 1.

The received signal via DL can be represented by this [6], [17]:

$$y_d(t) = \sqrt{P_t} h_d x(t) + n(t) \tag{1}$$

where $y_d(t)$ refers to received signal via the direct link, $\sqrt{P_t}$ is the transmitted power from eNB, h_d is the channel between eNB and RS,$n(t)$ is the additive white gaussian noise (AWGN) at destination [6], [18]. Half-duplex mode is considered in this work to avoid self-interference [19], [20] the time slot divided between the transmission and reception, therefore, the received radio frequency (RF) signal at first time slot t_1 is:

$$y_{ms}(t_1) = \sqrt{P_t} h_{\mathrm{m}}\, x(t_1) + \sqrt{P_m} h_a x(t_2) + n(t) \tag{2}$$

where h_{m} is the channel between eNB and $MSx(t)$ is the transmitted signal at any slot, $h_{\mathrm{a}}$is access link between MS, and user equipment (UE) is user equipment [6], [21].

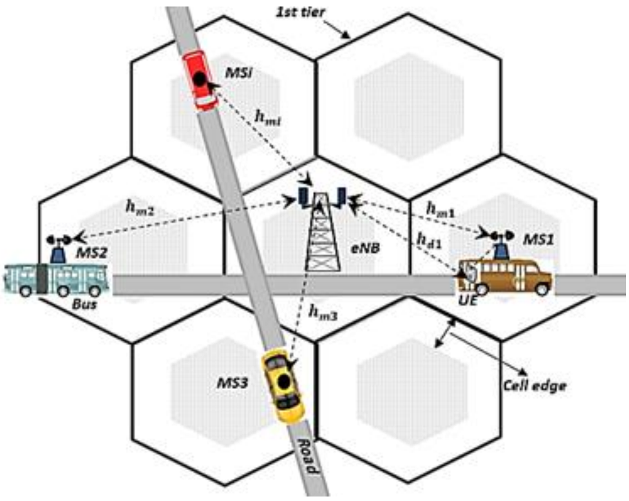

Figure 1. Proposed model for first tier cellular network using MS

MS is the mobile small station placed on the top of vehicle to increase the coverage and the capacity for the passengers especially when the vehicle or bus is pass at cell boundaries, ψ is amplification factor of amplify and forward mobile relay station was selected in this work, therefore the re-transmitted signal form MS at the t_1 can be write as:

$$x_{MS}(t_1) = \psi(\sqrt{P_t}h_{\mathrm{m}}\, x(t_1) + \sqrt{P_r}h_a x(t_2)) + n(t) \tag{3}$$

at the upload the user transmits $\sqrt{P_r}$ as the transmitted power, taking the expectation from the two sides [6], [22]:

$$E|x_{MS}(t_1)|^2 = E\left|\psi(\sqrt{P_t}h_{\mathrm{m}}\, x(t_1) + \sqrt{P_r}h_a x(t_2)) + n(t)\right|^2 \tag{4}$$

axiomatically that $E|x(t)|^2 = P$ (watt):

$$P_{MS} = \psi^2\left|\sqrt{P_t}h_{\mathrm{m}}\, x(t_1) + \sqrt{P_r}h_a x(t_2)) + n(t)\right|^2 \tag{5}$$

$$\psi = \sqrt{\frac{P_{MS}}{P_t|h_{\mathrm{m}}|^2 + P_r|h_{\mathrm{a}}|^2 + n(t)}} \tag{6}$$

while the received signal by the user attached with MS is:

$$y_r(t_2) = \psi\sqrt{P_t}h_{\mathrm{m}}x_{MS}(t_1) + n(t) \tag{7}$$

then,

$$y_r(t_2) = \psi\sqrt{P_t}h_{\mathrm{m}}\left(\psi\sqrt{P_t}h_{\mathrm{a}}\right) + n(t) \tag{8}$$

signal at the uplink can be explaind as follow:

$$y_{eNB}(t_2) = \sqrt{P_t}h_{\mathrm{d}} + \psi\sqrt{P_t}h_{\mathrm{m}}\sqrt{P_{MS}}h_{\mathrm{a}} + n(t) \tag{9}$$

and signal at the downlink is:

$$y_r(t_2) = \sqrt{P_t}h_{\mathrm{d}} + \psi\sqrt{P_t}h_{\mathrm{m}}\sqrt{P_{MS}}h_{\mathrm{a}} + n(t) \tag{10}$$

In order to evaluate the signal to noise ratio (SNR) for this system, there are very influencing factors such as, channel coefficient, quality of service (QoS), interference and noise [22], [21]. For simplicity, channel coefficient can be defined as $|h|^2 = K(\ell)^{-a}$ where a is the path-loss exponent which is dependent on the environment , ℓ is the length of distance between the sender and receiver , K is the transceivers' coefficients [22], [23] whereas, $K = G_t G_r h_t^2 h_r^2$, $(G_t h_t^2)$ and $(G_r h_r^2)$ are the gains and heights of the sender and receiver antennas, respectively, whereas ℓ is the distance between the source and destination. α (typically $\in \{2 - 5\}$ is the path-loss exponent, which is dependent on the environment [23]-[25].

Outage probability is the result of received SNR falls below a certain threshold γ_{th} [26]. The received signal at the MS via access link is expressed as (11):

$$\mathrm{P}_o^{ML} = \frac{1}{\gamma_{th}} e^{-snr_{ML}/\gamma_{th}}$$
$$\mathrm{P}_o^{ML} = P_r(snr_{ML} < \gamma_{th}) \cong \frac{\gamma_{th}}{snr_{ML}} \tag{11}$$

where the P_o^{ML}, $snr_{ML}$are the outage probability and SNR of mobile link. The same procedure the outage probability via access link (AL) as [27]:

$$\mathrm{P}_o^{AL} = \frac{1}{\gamma_{th}} e^{-snr_{AL}/\gamma_{th}}$$
$$\mathrm{P}_o^{AL} = P_r(snr_{AL} < \gamma_{th}) \cong \frac{\gamma_{th}}{snr_{AL}} \tag{12}$$

practically, the users also received signal from eNB station via direct link (DL) as shown in Figure 2, then the outage probability can be explained as [15]:

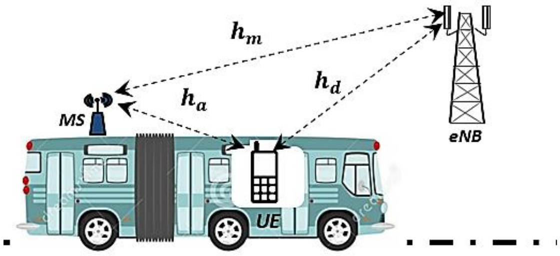

Figure 2. Available links direct, access and MS link for the vehicle user

$$\mathrm{P}_o^{DL} = \frac{1}{\gamma_{th}} e^{-snr_{DL}/\gamma_{th}}$$
$$\mathrm{P}_o^{DL} = P_r(snr_{DL} < \gamma_{th}) \cong \frac{\gamma_{th}}{snr_{DL}} \quad (13)$$

the users in vehicle received two signals from two links via mobile and access links, therefore the total SNR for the users in vehicle can be calculated by:

$$snr_T = snr_{DL} + snr_{MS} + snr_{AL} \quad (14)$$

where the $snr_d = \frac{\sqrt{P_t}h_{\mathrm{d}}}{n(t)}$ represents the SNR of the direct link and $snr_{ms} = \frac{\psi^2 P_t |h_{\mathrm{m}}|^2 |h_{\mathrm{a}}|^2}{(\psi^2 |h_{\mathrm{m}}|^2 + 1) n(t)}$ is the SNR via the mobile link. Obviously, average speed v of each vehicle as:

$$v = \frac{1}{\ell} \int_0^{\ell} \left(\frac{d\ell}{dt}\right) d\ell \quad (15)$$

then, $v = \Delta\ell / \Delta t$, $\Delta\ell = v\Delta t$, if we assume the vehicle travel in one direction the channel equation can be rewrite as:

$$|h|^2 = K(v\Delta t)^{-a}$$

and SNR for vehicle users can be rewrite as $snr_{ms} = \frac{\psi^2 P_t |h_{\mathrm{m}}|^2 |h_{\mathrm{a}}|^2}{(\psi^2 |K(v\Delta t)^{-a}|^2 + 1) n(t)}$. The bite rate for vehicle users with normalize the band width as [28]:

$$R_t = \frac{1}{2} log_2(1 + snr_T) \quad (16)$$

3. RESULTS AND DISCUSSION

This section is devoted to verifying the validity proposed model and evaluating the performance achieved by using MS to enhance the capacity and coverage area of vehicle users. In Figure 3, according to (11)-(13) the outage probability introduced for three different cases as a function of the average SNR for the direct and MS link. where, the blue curve shows the outage probability for DL only, that means, this link is inefficient for SNR values in comparison to proposed MS link.the blue curve indicates to enhancement in outage probability by using mobile station link in comparison to the direct link, this enhancement grows with increasing transmit power for a mobile station that installed on the vehicle as shown in the red curve in Figure 3. 1 explains the simulation parameters for the proposed system.

Figure 4 shows the simulation results in term of received signal strength (RSS) for MS link are evaluated along with mathematical analysis. We noted the good value of RSS at the near distance of eNB while this value will decrease with increasing the distance between the mobile station and eNB. On the other side, there is an improvement in the RSS by using MS in compared with DL; for example, at a distance 800m from eNB, the RSS increase from -70 dBm to -50 dBm, as shown in Figure 4.

Figure 5 shows the user bit rate (in Mbps) versus the vehicle speed for three tests DL (red), MS link (black) and DL with MS link (blue). This figure demonstrates that the bit rate of MS link outperforms the performance of the DL. On the other side the bit rate will increase than the other link by summation of both bit rates of DL and MS links. Conventionally, the bit rate will decrease with increasing the vehicle speed. By fixt MS on the top of vehicle the bit rate of the users via MS link is improved compared to direct link also using MS reduced effect of vehicle speed on the bit rate as demonstrate in Figure 5.

Table 1. Simulation parameters [23], [29]

Parameters Specifications	Value
Carrier frequency	2.5 G
Band width	20 M
Number of eNB	1
Antenna height of the eNB	25 (m)
eNB antenna gain	17 dBi
Max. Tx. power of eNB	46 dBm
Max. Tx. Power of MS	20 dBm
Path loss exponent (α)	3.7
Antenna height of the MS	3 m (above train or bus)
MS antenna gain	5 dBi
Antenna gain of UE	0 dBm
γ_{th}	30 dB

In public transportation where the number of users be larger, DL is insufficient to meet of required high capacity of all user's conjunction with high speed of vehicle. The best solution for this problem is using the MS. for example, number of users increased from 7 to 11 users for the same level of SNR by employing one MS on the top of vehicle as shown in Figure 6.

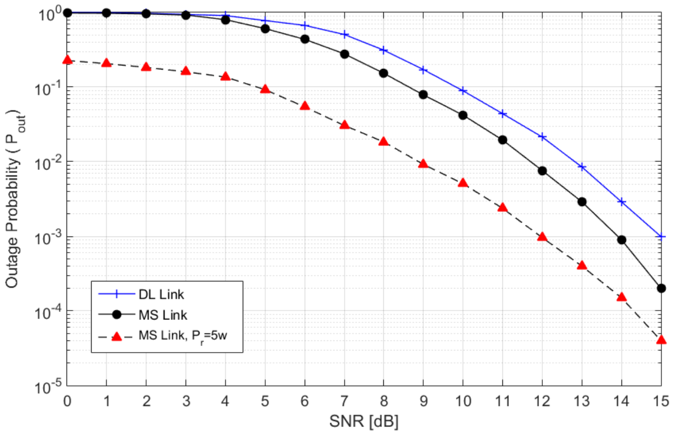

Figure 3. Outage probability enhancement for MS link relative to DL

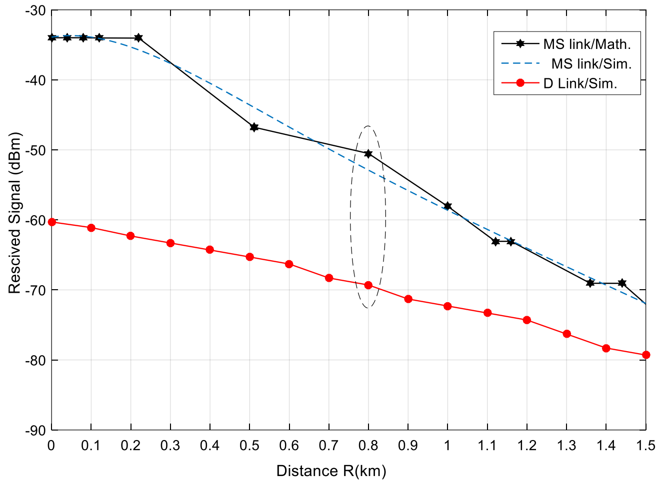

Figure 4. Relationship of received signal strength (RSS) versus both MS link and DL

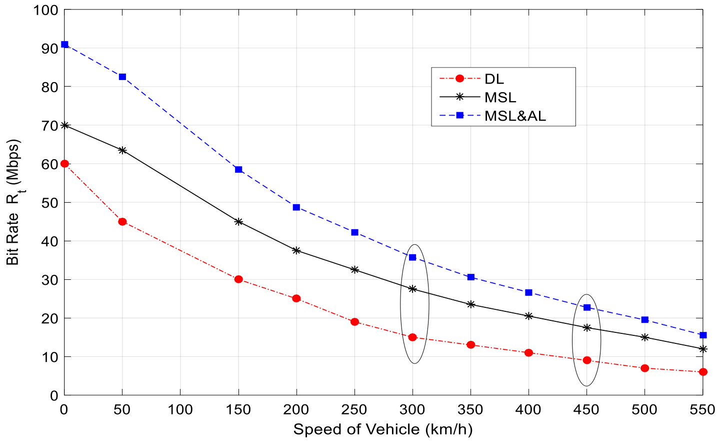

Figure 5. Relationship of bit rate of users versus vehicle speed regards to the used link

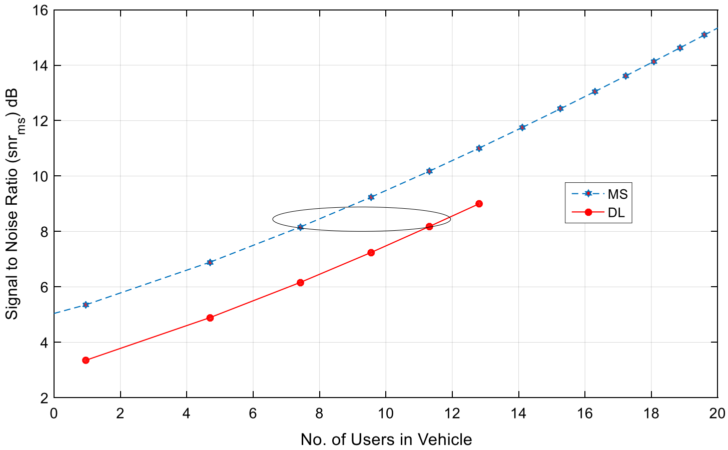

Figure 6. Increasing number of users by employing MS

4. CONCLUSION

One of the urgent problems that facing public transportation users and private vehicles is the interruptions in wireless services, especially with high speeds. This work presented the important solutions to overcome these interruptions, through using the mobile small cell station installed on the top of the vehicle to increase the received signal and improves the quality of services then increase the number of users inside the vehicles. These stations are connected to internal and external antennas. To obtain realistic results simulation results are extracted based on derivation of outage probability and SNR for the user. This work ensures reliable wireless connections especially, for high-speed vehicles and the crowded city, as a result, the number of users increases.

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