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EFFECT OF MOBILITY ON SINR IN LONG TERM EVOLUTION SYSTEMS

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Abstract

To meet the ongoing demands for high speed broadband communications, network providers are opting for the next generation of mobile technologies like LTE and LTE-Advanced. Standardized by 3GPP, these technologies aim to meet the requirements of higher data rates, low latency, and wider mobility, in varying environments without affecting the quality of service of a network. With higher mobility, the various network performance parameters like signal to interference to noise ratio, throughput, received signal strength indicator etc. get affected. This paper highlights the effect of mobility on signal to interference to noise ratio (SINR) characteristics of an IMT-A system in various test environments like In-house (INH), Urban Micro (UMi), Urban Macro (UMa), Rural Macro (RMa), and Suburban Macro (SMa). Simulations have been carried out to obtain spatial plots and SINR vs CDF plots in various test environments, at different user equipment speeds, emphasizing the effects of user equipment speed on the fast fading channel gainsand SINR of the system. By varying the UE speeds from 0 km/hr to 360 km/hr there was an increase in the minimum SINR value required for acceptable performance in a system. It was observed that for given system parameters, the minimum SINR required in RMa environment increased from -5dB to 1dB, in SMa environment it increased from -6dB to -2dB, and in case of UMa environment it increased from -4dB to 1dB, when the UE speed was increased from 0km/hr to 360km/hr. To address the problem of poor SINR in high mobility systems, 3GPP has introduced the technique of Moving Relays. It is used to improve the SINR and hence the channel quality for UEs moving at high speeds in LTE systems.

Keywords:

IMT-Advanced Systems, Channel Quality Indicator, User Equipment Speed, Signal to Interference to Noise Ratio, Fast Fading Gains

1. INTRODUCTION

The performance of any wireless mobile cellular communication system depends upon the quality of the received signal at the user equipment (UE). The various components like macroscopic path loss, shadowing, multipath fading, different types of interfering signals and receiver sensitivity determine the strength of the received signal at the UE and hence the overall throughput of the network [1]. To achieve higher data rates, the modulation and coding scheme to be adopted by the LTE-Advanced system, is determined by the channel quality indicator (CQI) value. This CQI value, fed back to the eNodeB by the UE during uplink transmission, determines the link quality of each UE. Till date many adaptive modulation and coding schemes (AMCS) have been worked upon wherein an MCS is adjusted every single transmission time interval [2]-[4]. The received SINR helps in selection of MCS, ensuring desired data rates at the UE while maintaining the BLER (Block Error Rate) at less than 10% in the downlink transmission [1]. Out of the many network performance parameters, SINR proves to be the best measurement parameter to determine the quality of the channels. CQI index, an indicator of the supportable data rate of a channel considers SINR at the UE and decides on the MCS to be adopted. Higher CQI value requires high SNR. Hence, CQI and SINR both play an important role in performance of a LTE-A system. Many SNR-CQI mapping schemes have been discussed in research articles like in [5]-[7]. In [8], Yu Chia-Hao et al. have shown how UE mobility affects the CQI value. Mobility results in degradation of the channel quality [9].

In [10], many channel models for various test environments have been defined. Work carried out in [11]-[15] by researchers discusses the path loss models which can be applied in the frequency range of 2-6GHz. The Table.1 gives the deployment scenarios for each test environment along with the respective channel models [10]. These test environments have been simulated and analysis of effect of UE speed on the system SINR has been presented in the following sections.

Table.1. Deployment Scenarios

Deployment scenario for the evaluation process	Indoor hotspot	Urban micro-cell	Urban macro-cell	Rural macro-cell	Suburban macro-cell
Inter-site distance	60 m	200 m	500 m	1732 m	1299 m
Channel model	Indoor hotspot (InH)	Urban micro-cell (Umi)	Urban macro-cell(Uma)	Rural macro-cell (RMa)	Suburban macro-cell (SMa)
User distribution	Randomly and uniformly distributed over area	Randomly and uniformly distributed over area. 50% users' outdoor (pedestrian users) and 50% of users indoors.	Randomly and uniformly distributed over area. 100% users outdoors in vehicles.	Randomly and uniformly distributed over area. 100% users outdoors in high speed vehicles.	Randomly and uniformly distributed over area. 50% users outdoor (vehicles users) and 50% of users indoors.

2. SINR AND CQI CALCULATIONS

SINR is a measure of signal quality used by operators to quantify the relationship between the RF conditions and throughput. UEs use SINR to calculate CQI which in turn is reported to the network.

As 3GPP specifications do not define SINR, UE does not report SINR to the network. SINR is internally measured by most UEs and recorded by drive test tools. SINR can also be calculated from *RSRQ* (Reference Signal Received Quality) values which in turn is calculated from *RSRP* (Reference Signal Received Power), *RSSI* (Received Signal Strength Indicator) and N_{prb} (number of Physical Resource Blocks) as shown in the following analysis.

$$RSRQ = N_{prb}\frac{RSRP}{RSSI} \quad \text{where } N_{prb} = \# RB_s \tag{1}$$

RSSI = wideband power = serving cell power + interference power + noise

$$RSSI = S_{tot} + I_{tot} + N_{tot}. \tag{2}$$

RSRP is measured over 1 resource element (RE) and *RSSI* per resource block (RB) is measured over 12 resource elements. Hence,

$$S_{tot} = x.12.N_{prb}RSRP \quad \text{where } x = \frac{RE}{RB} \tag{3}$$

$$I + N = \frac{I_{tot} + N_{tot}}{12.N_{prb}} \tag{4}$$

$$SINR = \frac{s}{I+N} = \frac{12.N_{prb}.RSRP}{(I_{tot} + N_{tot})} \tag{5}$$

$$= \frac{12.N_{prb}.RSRP}{(RSSI - S_{tot})}$$

$$SINR = \frac{12.N_{prb}.RSRP}{N_{prb}\frac{RSRP}{RSRQ} - x.12.N_{prb}.RSRP}$$

$$SINR = \frac{1}{\frac{1}{12.RSRQ}x} \tag{6}$$

The Table.2 states the values of the RF parameters of a network (RSRQ, RSRP and SINR) for different RF conditions.

Table.2. Network parameters for different RF conditions

RF Conditions	RSRP (dBm)	RSRQ (dB)	SINR (dB)
Excellent	>=-80	>=-10	>=20
Good	-80 to -90	-10 to -15	13 to 20
Mid Cell	-90 to -100	-15 to -20	0 to 13
Cell Edge	<=-100	< -20	<=0

The Channel Quality Indicator (CQI) index is an *N* bit integer, which contains information, provided by the UE to the eNodeB to indicate a suitable downlink transmission data rate, i.e., the Modulation and Coding Scheme (MCS) value. CQI value is based on the observed SINR at the UE and is used by eNodeB for downlink scheduling and link adaptation in LTE systems. For LTE network implementation, the CQI reporting interval can be fixed to (5ms or 10ms). Disadvantage of the fixed CQI reporting value is that it does not consider the dynamic changes in the channel conditions due to Doppler Effect. 3GPP standard provided the flexibility of selection of a CQI reporting interval value. If reporting time is too small, then quality of system performance improves as the eNodeB would be updated dynamically about the varying channel condition due to mobility. But this would reduce the uplink throughput in a system as the CQI will occupy transmission time interval (TTI) in the physical uplink control channel (PUCCH) or physical uplink synchronous channel (PUSCH). If the reporting time is large, than the downlink throughput will reduce, as the CQI value will become outdated resulting in requirement of retransmissions from eNodeB. Hence, the number of TTIs required by UE for transmission of its CQI report depends upon the channel conditions.

Using FDD technique, the UL bandwidth is divided into sub bands called physical resource blocks (PRBs). For a 10MHz bandwidth system, in all 50 PRBs are available out of which PUSCH uses 48 PRBs for data transmission and PUCCH uses 2 PRBs for control signaling. In time domain, users are allocated PRBs in each transmission time interval (TTI) which is of 1ms duration and there are 10 such sub frames in one frame. The Fig.1 shows the PRB and TTI allocation for DL/UL configuration.

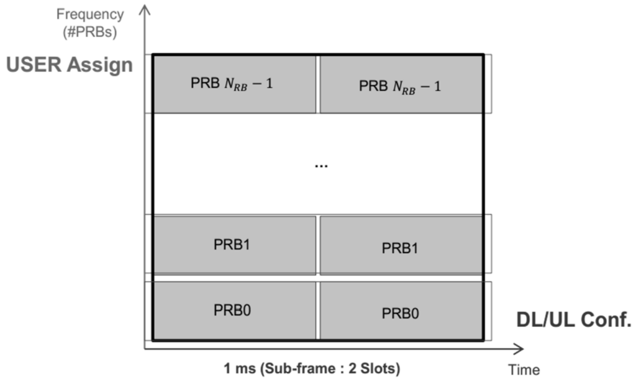


Fig.1. Physical Resource Block and Transmission Time Interval

As shown in Table.3, the number of PRBs allocated to the UE by the eNodeB, determines the bandwidth and hence the throughput of the system.

Table.3. Physical Resource Blocks for respective bandwidths

No. of PRBs	Bandwidth
6	1.4MHz
50	10.0MHz
100	20.0MHz

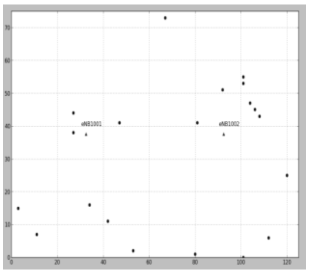
In LTE MIMO downlink scheduling, as per the CQI value from the UE, the multiuser scheduler allocates several RBs to the UE. eNodeB selects corresponding MCS and SNR values as shown in [16], [17]. Effective SINRs are then calculated as mentioned in [7]. CQI value for that group of RBs is then calculated.

More CQI bits (requiring more TTI) will be required by a UE with higher Doppler frequency (i.e. high speed) on account of rapid changes in the channel conditions. UE with low speed will use fewer CQI bits over 1 TTI. Thus mobility affects the CQI value, CQI reporting time value, TTI and hence the throughput of the network. Variable CQI reporting time exploits the feature of AMC in LTE systems. The carrier aggregation scheme used in LTE-Advanced systems, making use of component carriers in different bands experiencing different Doppler frequencies, experiences degraded frequency selective scheduling performance [18].

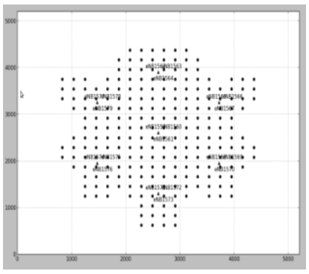
To best of our knowledge, till date, the effects of user's speeds on CQI value have been focussed upon [19], [8]. In this article, we have focussed on the effect of UE speed on SINR characteristic in LTE-advanced systems.

3. SYSTEM MODEL AND CONFIGURATION

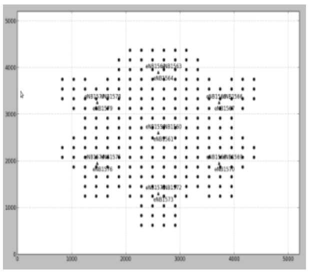
LTE/LTE-advanced system level simulator with full IMT-advanced channel model implementation has been used to analyse the effects of mobility of UE on SINR characteristics in various test environments [20]. AMacro cell scenario with hexagonal grid structure with 7 eNodeBs, 120 degree sectorization has been considered. The Fig.2, shows the UE and eNodeB placements in four different scenarios - InH (In-house), UMA (Urban Macro), SMa (Suburban Macro) and RMa (Rural Macro).



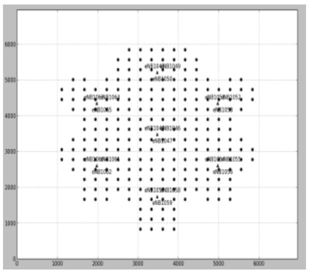
InH (Indoor hotspot) scenario



Uma(Urban macro) scenario



SMa(Suburban macro) scenario



RMa (Rural macro-cell) scenario

Fig.2. UE and eNB placements in scenarios

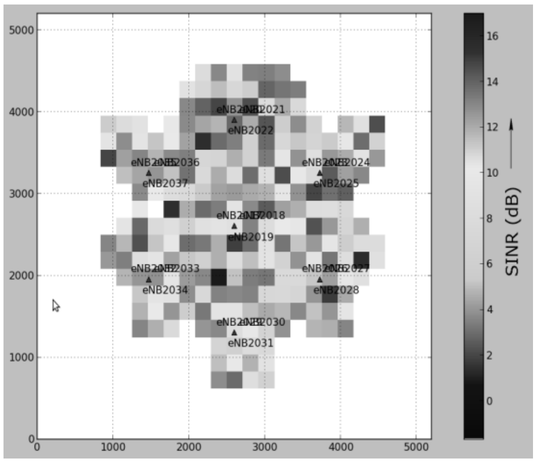
Simulations have been carried out for 100 TTI and UE speed has been varied from 0-360 km/hr. The Table.4 gives system parameters for the simulations carried out in this work.

Table.4. Simulation Parameters for IMTA-PHY

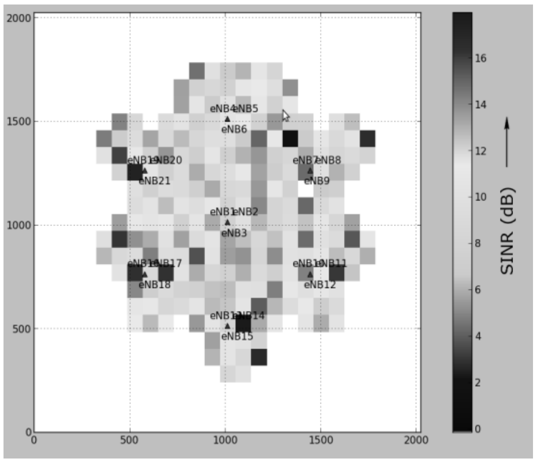
Parameter	**Value**
Carrier frequency	2GHz
Bandwidth	10MHz
Full buffer	True
Number of MS Antennas	2
Number of BS Antennas	2
Number of UE per eNodeB	10
Number of DLPRBs	50
Number of ULPRBs	50
Feedback Delay	6 TTI
CQIUpdate	5ms
DL Scheduler	Proportional Fair
PfAlpha	0.001
Precoding Mode	Closed Loop Codebook Based
Power Control : Po dBm per PRB	-80.0 to -84.0dBm (InH to RMa)
UE speed	0 to 360Km/hr

4. ANALYSIS OF SIMULATION RESULTS

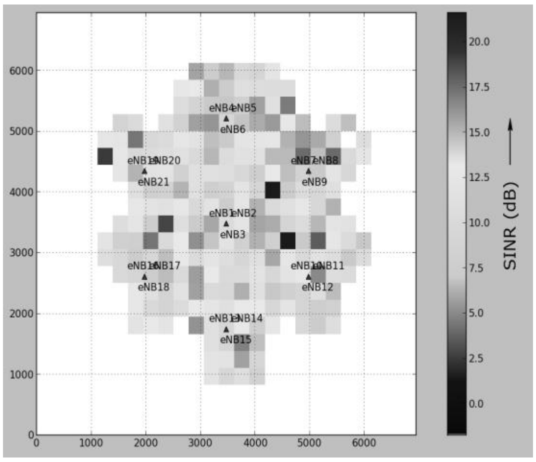
The received SINR at the eNodeB, during uplink, in different scenarios, have been shown in Fig.3. It can be seen from the figure that high SINR values are received in suburban environment as compared to rural environment. This is because higher UEspeeds are possible in case of rural environments as compared to suburban and urban scenarios. As mobility increases, channel quality degrades which in turn affects the SINR and CQI values at the UE and eNodeB respectively. This in turn affects the MCS and hence the throughput of the system.



Received SINR in SMa scenario



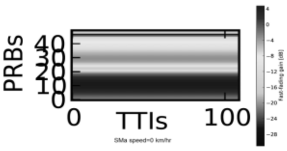
Received SINR in UMa scenario



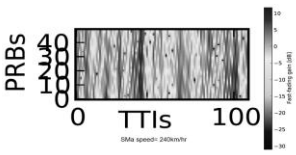
Received SINR in RMa scenario

Fig.3. SINR received at eNodeB during uplink in different scenarios at speed of 240 km/hr

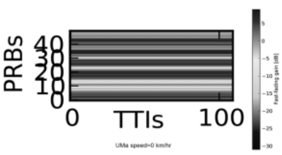
The Fig.4 depicts the fast fading gain plots for different scenarios at different UE speeds of 0 km/hr and 240 km/hr. It shows how fast fading gain gets affected by the speed of the UE due to multipath. For stationery UE, each PRB experiences a constant path loss over a period of 100 ms. As the UE speed increases, the channel experiences vast variations in fast fading gains of a PRB during the 100 ms TTI. In case of urban environment, high UE speeds are not possible, but there are diffractions and reflections from the surrounding buildings. This results in multipath fading, causing more variations in the fast fading gains. It is seen that at 0 km/hr the fast fading gains remain in the range of -5 to 5dB, but as UE speed increases the Doppler effects causes the gains to drop to lower values of -20dB at some instances. In case of SMa scenario, the variations in fast fading gains are comparatively less than UMa but more than RMa scenario. This is because, here higher UE speeds are possible as compared to UMa environments but since the density of buildings is less in SMa scenario, the multipath fading is less resulting in proportionately stronger SINR values and better channel quality. In Rural areas, high UE speeds are possible resulting in larger Doppler shifts, but since the Rayleigh fadings in open areas are comparatively less, higher SINR values and stronger channel conditions are available. Here the fast fading gains are in the range of 0dB to 4dB and drops to -20dB range only in rare case.



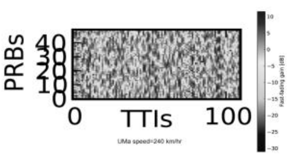
SMa Speed=0 km/hr



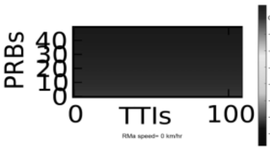
SMa Speed=240 km/hr



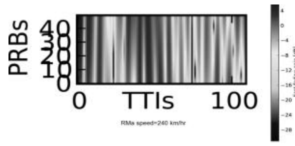
UMa speed=0 km/hr



UMa speed=240 km/hr



RMa Speed=0 km/hr

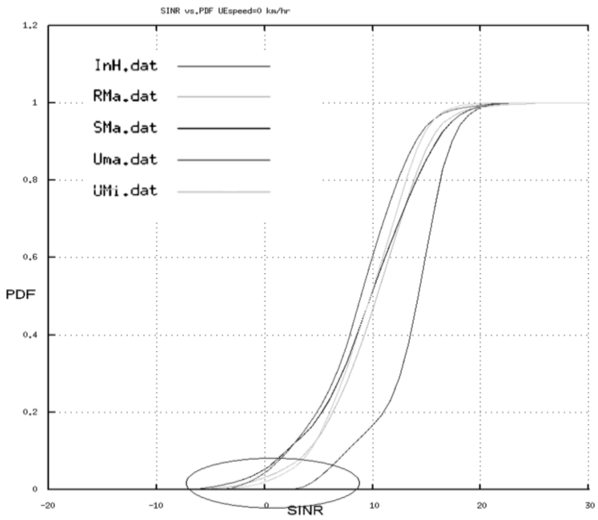


RMa Speed= 240 km/hr

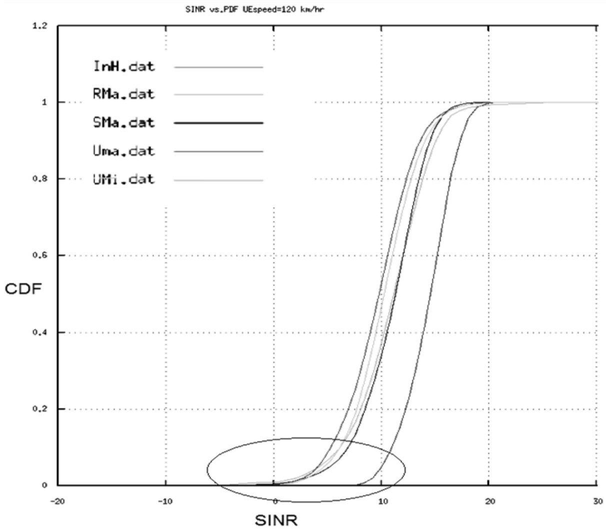
Fig.4. PRB vs. TTI plots for different scenarios

The SINR vs PDF plots shown in Fig.5 represent the effect of mobility on SINR in different environments. It can be observed from the plots that as the UE speed increases from 0 km/hr to 360 km/hr, the minimum required SINR value in every environment increases. This signifies the fact that as UE speed increases, the channel quality of the system starts degrading and hence higher SINR values are required by a system to meet the desired quality of performance. The Table.5 summarizes the minimum SINR values required at four different UE speeds in every environment. In case of InH environment, UE speed is not considered and the minimum SINR values are constant and depend upon the penetration losses as well. In rest of the cases we can observe that as UE speed increases there is steady increase in the minimum SINR required.

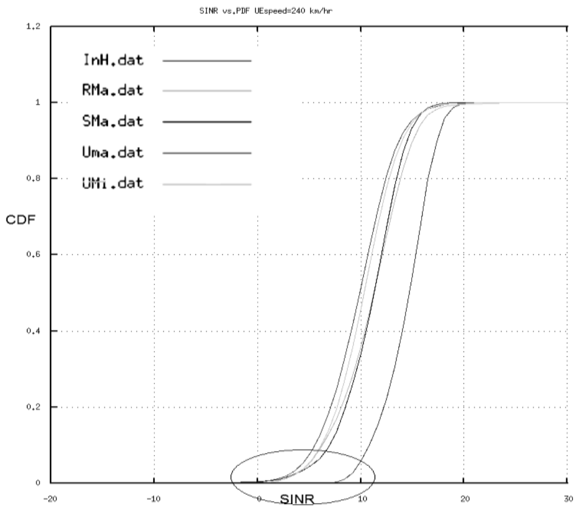
More processing of signals will have to take place in case of UMa environmental setups, as compared to InH, RMa, SMa and UMi test environments, to achieve the acceptable quality in the network. As speed increases Doppler Effect also tend to cause path losses, resulting in low SINR. Reflections from surroundings, scattering loses, short term fading etc. affect the signal strength. The UE will also encounter handovers from one eNodeB to another while it is on move. If the handoff does not complete, channel deteriorates and finally call drops. With high speed, the user reaches the cell edges very quickly. Hence the interference from neighboring UEs and secondary eNodeBs also increases, resulting in poor SINR. For a given quality of service, systems having UE with lower speeds can tolerate lower SINR values as compared to systems having higher UE speeds. Hence mobility has great impact on the allowable SINR values of a system and the problem has to be addressed properly.



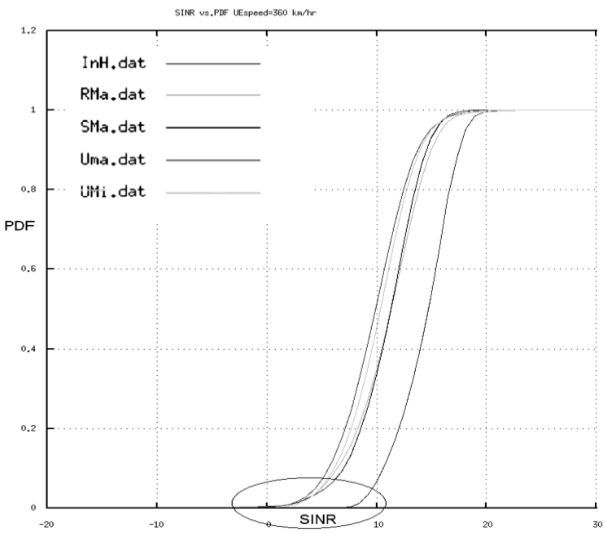
(a) UE speed = 0 km/hr



(b) UE speed = 120km/hr



(c) UE speed = 240km/hr



(d) UE speed = 360 km/hr

Fig.5. SINR vs. PDF at different speeds at different scenarios

Table.5. UE Speed vs minimum required SINR

Speed (km/hr.)	Environment	SINR (dB)
0	SMa	-6
	UMi	-5
	UMa	-4
	RMa	-5
	InH	3
120	SMa	-2
	UMi	0
	UMa	-1
	RMa	-4
	InH	8
240	SMa	-2
	UMi	1
	UMa	0
	RMa	0
	InH	8
360	SMa	-1
	UMi	2
	UMa	1
	RMa	1
	InH	8

To solve this problem, the technological component of relaying was introduced in LTE-advanced systems [21]. With further development in relaying technology, moving relay concept was proposed to mitigate the Doppler effects experienced by high speed users. Herein relay nodes are implemented on top of the public transport, providing strong signal strength to users on board of a high speed vehicle. This solves the problem of coverage at cell edges and also ensures that signal strength quality is maintained all along the UE travelling path. SINR of systems with MRNs has always proved to be better than FRN systems. This has been discussed by researchers in [22]-[26].

5. CONCLUSION

Mobility affects the signal strength at the UE. The SINR of a system depends on the quality of signal at the UE. This value of SINR is used to calculate the CQI value which is fed back by the UE to the eNodeB. Depending on this CQI value, appropriate MCS is selected by eNodeB and the system performance can be improved. Doppler Effect, encountered in systems with UEs travelling at higher speeds, can be mitigated by the Adaptive Coding and Modulation (ACM) techniques. Also, system environment affects the SINR. In UMa environment, UE speed is lower than in case of RMa environment hence the Doppler Effect also decreases and such systems require lower SINR values to meet the same quality of service. The moving relay technology introduced by 3GPP in LTE-Advanced systems is a promising solution to improve the SINR of systems with high speed users. Further work needs to be carried out in the area of moving relay nodes.

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