# Monitoring Vehicular User Mobility to Predict Traffic Status and Manage Radio Resources

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***Abstract*—Mobile communication is one of the most ubiquitously used technologies in contemporary world, evolving towards its fifth generation (5G). In day-to-day scenarios, many vehicular users avail broadband cellular services while traveling. The density of such vehicular users change dynamically in a cell and at certain sites (e.g. signal lights), traffic jams would arise frequently. Such conditions would pose high load situation to respective serving base station. As a consequence, the cell site would experience high dropping and blocking rates and subject its users to poor Quality of Experience (QoE). In this work, mobility behavior of vehicular users are analyzed and an algorithm is designed to predict traffic status of a cell. The proposed traffic prediction algorithm is a coalition strategy consisting of schemes to predict user cell transition, vehicular cluster/moving network detection, user velocity monitoring etc. The traffic status indication provided by the algorithm could be used to design efficient radio resource management (RRM) techniques. In the presented paper, this context information about traffic severity is used to pro-actively initiate load balancing at corresponding site and release resources. Further, appropriate small cells are activated/deactivated based on formation/dispersion of traffic jams respectively. The simulation results exhibit substantial reductions in dropping and blocking of users, demonstrating improved QoE of users.**

***Index Terms*- 5G, vehicular user cluster, moving network, traffic status prediction, context information, RRM**

## I. Introduction

Mobile communication is one of the key technologies in today's world with ever increasing number of mobile subscriptions [1], and on the verge of its fifth generation (5G). Due to the popularity of mobile multimedia services, there is a drastic increase in data traffic demand of mobile users[2]. Further, the number of connected devices have been growing exponentially and is anticipated to reach the figure of 50 billion by the year 2020 [1]. At this pace, by year 2020 number of connected devices is anticipated to be around 10 to 100 times more than present and traffic volume would be 1000 times larger. Thus, 5G mobile communications face key challenges of satiating high data traffic volume demand and accommodating higher number of connected devices in the network[3].

In real world scenarios, mobile users traveling in vehicles avail cellular broadband services (e.g. infotainment in car, individual commuter usage in public transport etc.). Density of such vehicular users in a cell varies dynamically based on road topology, arrival/departure rate etc. At certain sites (e.g. signal post), traffic jams are more frequent. In such sites, large number of vehicular users are at momentary halt, posing high load situation to serving base station. The resulting congestion leads to dropping of several already connected users in the cell and blocking of access attempts made by newly entered users to the cell. These factors will negatively impact the QoE of users in the cell. The knowledge of traffic status in a cell will enable efficient design of radio resource management, with a motive to improve QoE of users even in highly congested traffic jams.

Many schemes are present in literature to combat high load situation arising from congestion, such as coverage adaption, channel borrowing [4], mobility load balancing [5], heterogeneous access management [6] etc. But these schemes are required to be proactively triggered based on knowledge of traffic severity, in order to achieve efficient performance. Further, there are certain works in literature to detect hotspot situation in a cell [7][8]. Majority of these works consider high user arrival rate, low departure rate, or increased bandwidth demand of existing users causing hotspot situation in a cell. Further, blocking/dropping rates and network load figures are investigated to evaluate congestion status in a cell. However, these solutions do not rely on the knowledge of realistic traffic jam formations in a cell, to initiate suitable RRM strategies well in advance.

In addition to this, there are various methods to predict urban traffic jams based on feedback from large historic traffic data and a large number of trajectory tracking devices and traffic sensors [9], based on 2D cellular automata model [10], based on fuzzy search theory [11] and few based on video surveillance systems [12] [13]. The above schemes are typically used to predict general traffic congestion, associated delays and convey these information to transport systems. However, these schemes are costly in terms of computation and infrastructure and are not necessarily designed from cellular network perspective. This renders the aforementioned solutions not suitable for usage in cellular networks.

In this paper, a framework is proposed to predict vehicular traffic status from cellular network perspective and study its impact on cellular network. Vehicular user mobility is monitored and schemes for user-cell transition prediction, vehicular cluster/moving networks detection, vehicular velocity monitoring are combined to design traffic status prediction algorithm. This a-priori context information about traffic jam formation is utilized to proactively initiate load balancing at serving base station or activate small cell at anticipated site of frequent traffic jams (e.g., signal posts, cross roads etc.). Thus, high load situation at traffic jams are relieved and QoE of users is improved even during traffic jams.

The remainder of this paper is organized as follows: Section II deals with prediction of traffic relying on vehicular user mobility, cell transition prediction and vehicular user cluster detection. Section III discusses simulation setup, traffic status prediction results and improvements in Key Performance Indicators (KPIs), and Section IV provides a conclusion and indicates future work.

## II. Traffic status prediction

Due to the popularity of cellular broadband services, vehicular users have begun demanding substantial data traffic from network while on the move. Thus, load situation in a cell vary with respect to mobility of vehicular users in and out of it. In real world scenarios, several vehicular users travel into a cell (as per road topology) and at certain sites (e.g., signal posts) form traffic jams frequently. When high number of such traffic demanding vehicular users are momentarily stagnant in a cell, hotspot situation is posed to the serving base station.

Figure. 1 shows an example of such traffic jam formation from cellular network's perspective. Cell 0 has signal posts where vehicular users arrive from neighboring cells and eventually stop to give rise to traffic jams. After a while, vehicular users would start their travel again, dispersing the jam. The traffic status of cell 0 varies accordingly. Thus, by monitoring the mobility of vehicular users in neighboring cells of cell 0 (site of frequent traffic jams), substantial information could be gathered to predict traffic status of the cell in near future. Knowledge of such information can be used to free up resources preemptively via load balancing or appropriately activate small cells near to anticipated traffic jam site and accommodate newly entering vehicular users.

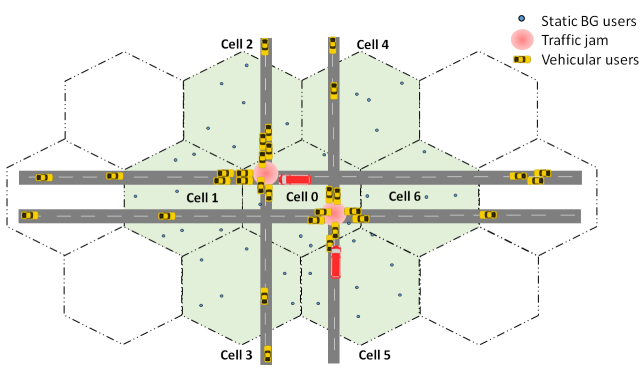


Fig. 1. Traffic jam formation scenario

### A. System model

Figure. 2 depicts the system model considered to monitor vehicular users traveling towards site of interest and obtain substantial statistics required to design traffic status prediction algorithm. Cell 0 is the site of interest where traffic jams occur frequently (due to presence of signal posts etc.). The vehicular users' mobility behavior in cells neighboring to this site are monitored and those that are traveling towards cell 0 are investigated. Such users are identified when Eq. 1 is satisfied.

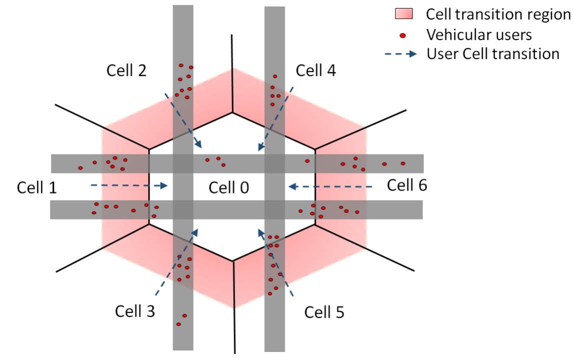


Fig. 2. Traffic jam formation model

$$\frac{\sqrt{(x_b - x_n(i))^2 + (y_b - y_n(i))^2}}{\sqrt{(x_b - x_n(i-1))^2 + (y_b - y_n(i-1))^2}} < \quad 1, \qquad (1)$$

where, $(x_b,y_b)$ denotes position of base station (cell 0), $(x_n(i),\ y_n(i))$ is the present location of vehicular user $n$, and $(x_n(i-1),\ y_n(i-1))$ is its past position. Further, in the considered system model, a transition region is defined at boundaries of neighboring cells. A user is in transition region if Eq. 2 is satisfied:

$$g_s < \theta_t, \qquad (2)$$

where $g_s$ is the geometry experienced by the user with respect to serving base station and $\theta_t$ is a threshold value used to set cell transition region, which is derived from radio propagation data. Geometry is defined as ratio of power received from serving base station ($P_k$) to received interference power from other base stations ($P_j$), given by

$$g_s = \frac{P_k}{\sum_{j \neq k} P_j} \qquad (3)$$

The group of vehicular users satisfying Eq. 1 are monitored and below statistics are obtained to design algorithm to predict traffic severity at the site of interest (cell 0):

1) $N_t$ $\rightarrow$ number of vehicular users in transition region of neighboring cells, having cell 0 as next cell for transition.
2) $N_{Ct}$ $\rightarrow$ number of vehicular user clusters in transition region of neighboring cells, having cell 0 as predicted next cell.
3) $N_0$ $\rightarrow$ number of vehicular users already transited to cell 0 from neighboring cells.
4) $T_t$ $\rightarrow$ total data traffic demand of vehicular users in transition region of neighboring cells.
5) $N_{\Delta vj}$ $\rightarrow$ number of vehicular users with negative velocity gradient, nearby frequent jam location.

6) $N_{C\Delta vj} \rightarrow$ number of vehicular user clusters with negative velocity gradient, nearby frequent jam location.
7) $T_{\Delta vj} \rightarrow$ cumulative data traffic demand of vehicular users with negative velocity gradient, nearby frequent jam location.

### B. Cell transition prediction

When a vehicular user is in transition region specified by Eq. 2, then future cell for its transition has to be predicted. By this process, statistics about vehicular users or vehicular user clusters that would travel to cell 0 in near future, can be obtained. These statistics are substantial for traffic status prediction of cell 0. In this work, an unsophisticated scheme based on vehicular user geometry (in dB) is incorporated to predict future cell association of a vehicular user. The geometry values of vehicular users are obtained at regular sampling intervals. The potential cells for user transition can be shortlisted from neighboring cells based on whether user geometry values have positive gradient with respect to a particular cell. Such behavior indicates that a vehicular user is advancing towards considered cell and would transit into it. The transition probabilities derived from the scheme are given by:

$$p_1 = \frac{g_1}{g_1 + g_2}, \quad (4)$$

$$p_2 = \frac{g_2}{g_1 + g_2}, \quad (5)$$

where $g_1$ and $g_2$ are geometries of a vehicular user with respect to two probable cells for user transition.

There are several other schemes in literature to predict future cells of a user based on machine learning [14], route clustering [15], neural networks [16] etc. However, such schemes have high computational complexity and cost. Hence, cell transition prediction based on simple geometry measurements [17] is used in this work.

### C. Detection of vehicular user clusters

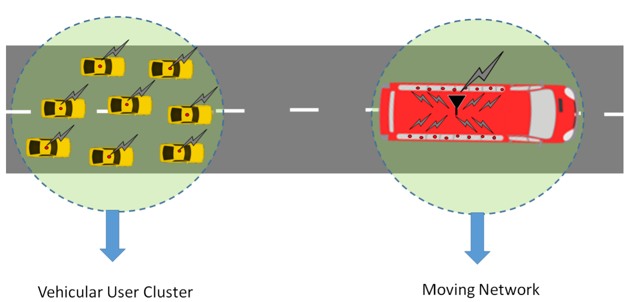


Fig. 3. Vehicular user cluster

During peak time of the day, several vehicular users travel in a group from various locations and at certain sites such as signal posts make a brief halt, giving rise to traffic jams. Thus, detection of such vehicular user clusters in and around the site of frequent traffic jam is a valuable indicator in prediction of traffic jams, which would arise in near future.

Figure. 3 shows such a vehicular cluster. It also depicts another variant called moving network, wherein many users traveling together (e.g. in bus, tram etc.) avail cellular services, but their access to the cellular network is managed by a locally present access point. Presence of vehicular user clusters is identified by following algorithm:

**Data**:
1) Positions of vehicular users in each neighboring cell satisfying Eq. 1
2) Predefined values for cluster radius ($R$) and minimum number of vehicular users required to form a cluster ($\theta_{NR}$)

**Step 1:**

Obtain distances among all vehicular users in each cell satisfying Eq. 1

**for** $i = 1$ to $N$
  **for** $j = 1$ to $N$
    **if** $i \neq j$ **then**
      obtain $d_{ij}$
    **end if**
  **end for**
**end for**

where, $N$ is the number of vehicular users approaching, $i, j \in (1, 2, ..., N)$, $d_{ij}$ is the distance between users $i$ and $j$.

**Step 2:**

Find the maximum number of users $N_R$ present in a radius $R$ around user $k$, advancing in same direction.
$\forall \; k \in (1, 2, ..., N)$, determine the $k$ which satisfies Eq. 6 more number of times.

$$d_{kj} <= R \quad (6)$$

**Step 3:**

If Eq. 7 is satisfied, then a vehicular cluster exists.

$$N_R >= \theta_{NR}, \quad (7)$$

**Algorithm 1:** Vehicular cluster detection

### D. Traffic status prediction & proactive RRM

Based on the collected statistics of vehicular user activity in and around site of interest (in this case cell 0), traffic status prediction algorithm is designed. The vehicular users are assumed to request full buffer data traffic (the buffers of the users' data flows always have unlimited amount of data to transmit [19] ), hence constituting a worst case scenario. The traffic status indicator (TSI) would assume one of the following states:

**a) Green:** There are not enough vehicular users/clusters/moving networks in cell 0 or in transition region of cells neighboring to it, to form a traffic jam or pose a congestion situation in near future. The cumulative data traffic demand and number of access attempts made by vehicular users to cell 0 are minimal and there is no indication of high load situation occurring soon. The statistics about data traffic demand are considered because, in certain cases even though there are not enough users present in traffic jam physically, cumulative data traffic demanded by them might be high enough to cause congestion. Equation. 8 defines the condition for TSI to be green:

$$(N_t < \theta_N) \wedge (N_{Ct} < \theta_{Ct}) \wedge (N_0 < \theta_0) \\ \wedge (T_t + T_{\Delta vj} < \theta_{T\Delta vj}), \tag{8}$$

where $\wedge$ indicates the logical AND operation.

**b) Yellow:** This state indicates that high traffic situation is likely to happen in near future of the cell. Sufficient number of vehicular users/moving networks will already be in transition region expected to enter cell 0 or cumulative data traffic demand of vehicular users in transition zone is large enough to pose hotspot situation in cell 0 in the time coming. Eq. 9 denotes the condition for TSI to be yellow. Eq. 9 also investigates if the sum of vehicular users in transition region and those already moved to cell 0 are large enough to pose high load situation:

$$(N_t > \theta_N) \vee (N_{Ct} > \theta_{Ct}) \\ \vee (N_t + N_0 > \theta_{N0}) \vee (T_t > \theta_{Tt}), \tag{9}$$

where $\vee$ indicates the logical OR operation.

As soon as TSI is yellow, load balancing can be triggered proactively to free up resources. This enables cell 0 to accommodate soon to enter vehicular users, already in transition region. Figure. 4 depicts the process of load balancing (LB) used in this work, where static background users present in boundary of cell 0 are deliberately made to be served by appropriate neighboring base stations. Care should be taken that LB is not carried out on vehicular users, since their movement would lead to higher LB failures and ping-pong handovers.

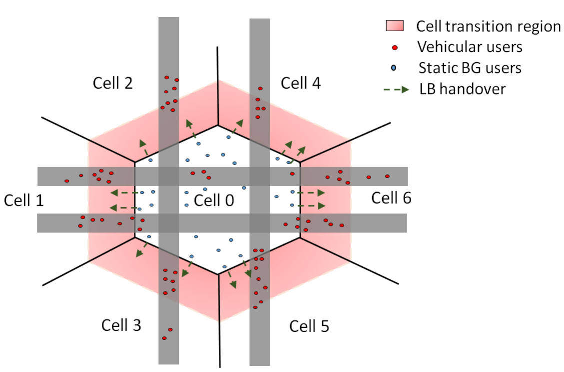


Fig. 4. Proactive load balancing

**c) Red:** If Eq. 10 is satisfied, then it indicates that traffic jam is imminent at frequent jam site. The vehicles typically apply brakes and slow down when they are supposed to halt at signal posts. Eq. 10 makes use of such behavior and considers statistics of vehicular users/moving networks near jam site, with negative velocity gradient and their cumulative data traffic demand. To assist the attainment of these statistics, a predefined radius around anticipated jam site is used and vehicular users contained in it are investigated. Velocity estimation by Doppler processing [18] is assumed to be present in the considered system.

$$(N_{\Delta vj} > \theta_{\Delta vj}) \vee (N_{C\Delta vj} > \theta_{C\Delta vj}) \\ \vee (T_{\Delta vj} > \theta_{T\Delta vj}). \tag{10}$$

The threshold values $\theta_N$, $\theta_{Ct}$, $\theta_0$, $\theta_{T\Delta vj}$, $\theta_{N0}$, $\theta_{Tt}$, $\theta_{\Delta vj}$ and $\theta_{C\Delta vj}$ have to be set by the network operator on the basis of available resources at site of interest and maximum number of connections that could be served. The thresholds can be fine tuned by the operators suitably.

Once the TSI is red with respect to a frequent jam site (e.g. signal post), nearest small cell to the site is activated. The vehicular users in traffic jam, which is bound to happen at the site, will now be served by the small cell (SC). Figure. 5 demonstrates the activation of SC at frequent traffic jam site.

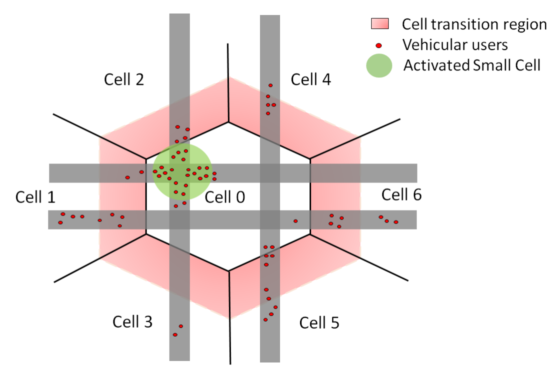


Fig. 5. Small cell activation

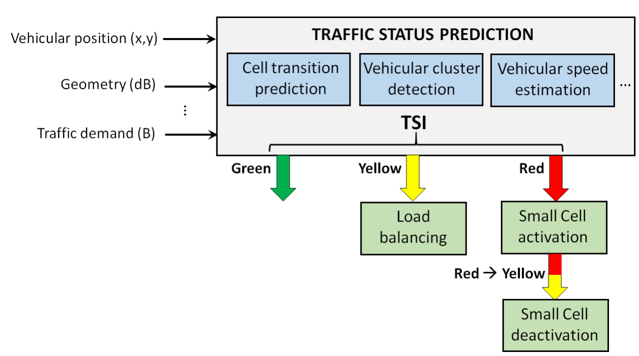


Fig. 6. Overall framework

Further, as the vehicular users start their travel again and traffic jam disperses, TSI changes accordingly to yellow and then to green. Small cell is deactivated proactively once traffic jam disperses, to minimize energy consumption of small cells. The overall framework of traffic status prediction and proactive RRM is depicted in Fig. 6.

## III. Evaluation Results

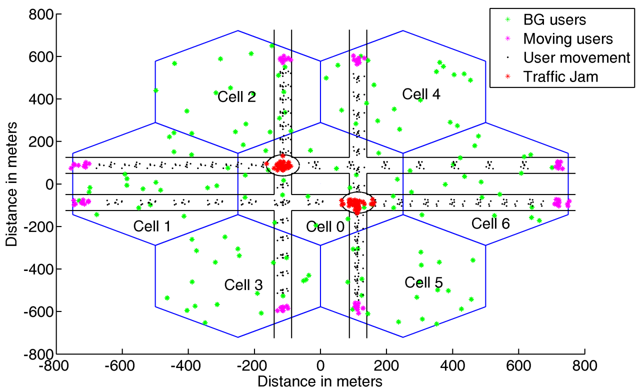


Fig. 7. Simulation of traffic jam formation

A LTE system level simulator is used to set up a multi-cell scenario as shown in Fig. 7. Each cell has base station in its center and has several static background users in it. Evaluation methodology follows [19] and assumes 10 MHz bandwidth for LTE operation at 2 GHz. In the used system model, cell 0 is the site of interest where there are crossroads in which traffic jams occur frequently. The vehicular users originate from neighboring cells and travel into cell 0 as per road topology, and cause traffic jams. Table I summarizes simulation parameters. The thresholds are set as $\theta_N = 30$, $\theta_{Ct} = 3$, $\theta_0 = 45$, $\theta_{N0} = 45$, $\theta_{C\Delta vj} = 3$, $\theta_{\Delta vj} = 30$, $\theta_{T\Delta vj} = 250$ MB, $\theta_{Tt} = 250$ MB $\theta_{NR} = 5$and $R = 30m$.

TABLE I
Simulation Parameters

| Parameter | Assumption |
|---|---|
| Carrier frequency | 2 GHz |
| System bandwidth | 10 MHz (50 PRBs) |
| Total transmit power | 40 W (s2s=500 m)<br>10 W (s2s=250 m)(small cell) |
| Shadowing | log-normal<br>Standard deviation: 8 dB<br>Decorrelation distance: 50 m |
| Fast fading | 2-tap Rayleigh fading channel |
| Noise power | $-174$ dBm/Hz + $10 \cdot \log_{10}(B) + 7$ |
| Background users per cell | 30 |
| Vehicular users | 135 at velocity ranging from $30 - 80$ km/h |
| Monitoring interval | 1 second |

As the simulation advances, vehicular users travel from neighboring cells to cell 0 and based on algorithm presented in section II-D, TSI is predicted. The TSI evolution with time is shown in Fig. 8. At the start of simulation, TSI at cell 0 is green since there is neither enough number of vehicular users in cell 0 nor in transit region of neighboring cells. Once

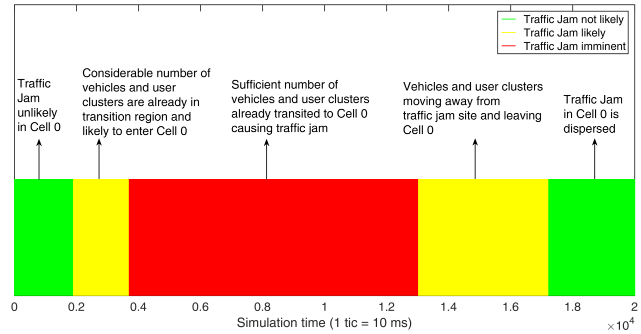


Fig. 8. Traffic status indicator

there are sufficient vehicular users/clusters ready to transit to cell0, TSI changes to yellow. Further, when sufficient number of vehicular users/moving networks enter cell 0 and show indication of halting near traffic jam site (negative velocity gradient), TSI becomes red. The TSI remains red for the entirety of traffic jam and as soon as vehicular users begin to disperse TSI changes from red to yellow again. Finally, when majority of vehicular users move out of cell 0, TSI returns to green.

When TSI is yellow, load balancing is initiated proactively at the site of cell 0. (Note: LB initiated only once, when TSI changes from green to yellow) The static background users near cell boundary in cell 0 are load balanced. This context aware procedure frees up some resources for incoming vehicular users to cell 0 in near future. This procedure reduces dropping of users by $\approx$ 18%, blocking of new access attempts by $\approx$ 10% and blocked handover attempts by $\approx$ 18% (shown in Fig. 9 a)). Further, when TSI turns red, relevant small cells are activated to serve the vehicular users at respective traffic jams. In the presented evaluation, traffic jams occur almost simultaneously at two sites as depicted in Fig. 7. By the activation of small cells, dropping of users is reduced by $\approx$ 82%, blocked access attempts is reduced by $\approx$ 42% and blocked handovers are reduced by $\approx$ 81% (shown in Fig. 9 b)). The reduction of these KPIs, indicate that users have improved QoE even during traffic jams.

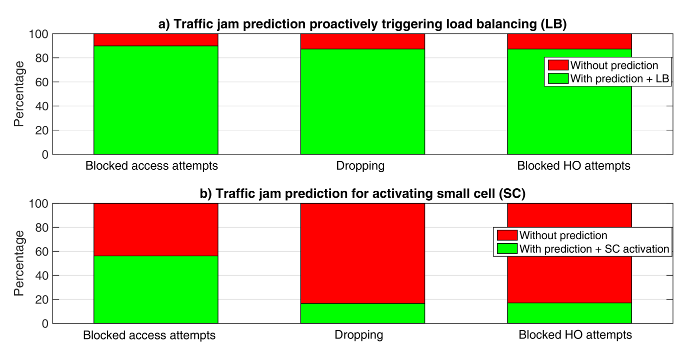


Fig. 9. Improvements in KPIs

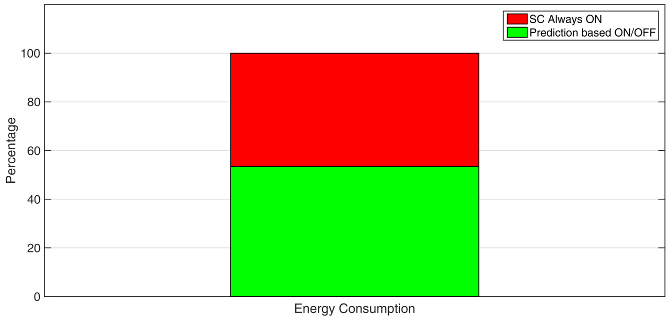


Fig. 10. Comparison of energy consumption

Further, when the traffic jam disperses (TSI change from red to yellow), activated small cell is switched off. Figure. 10 compares the energy consumption when small cell is always ON vs prediction based ON/OFF. With prediction based scheme, energy consumption is reduced by $\approx 45\%$ for considered simulation set up. Thus, prediction based small cell activation/deactivation not only improves user QoE but also is energy efficient compared to always ON strategy.

## IV. Conclusion and future work

In fifth generation (5G) of mobile communications, severe challenge will be posed by higher data traffic volume (1000 times more) and larger number of connected devices ($10-100$ times more). Further, popularity of broadband multimedia services has been resulting in increase of vehicular users availing such services. In day-to-day scenarios, large number of such vehicular users travel in and out of a cell, changing its data traffic load. At certain sites, traffic jams occur frequently leading to hotspot situation in the serving cell. This leads to higher dropping/blocking of users thereby hindering their QoE. In forthcoming 5G systems, better QoE is expected by users irrespective of high load situations caused by traffic jams. This paper proposed a framework to indicate traffic status of a cell and predict occurrence of traffic jams at specific sites. The mobility behavior of vehicular users in and around the site of interest were investigated and traffic status indicator was designed from cellular network perspective. The supplementary concepts such as cell transition prediction and vehicular cluster detection were discussed as well. Further, RRM strategies namely traffic status aware load balancing and small cell activation/deactivation were presented, which work in tandem with traffic prediction framework. These proactive RRM schemes resulted in substantial reductions in blocking/dropping of users and blocked handover attempts, demonstrating better QoE for users even in traffic jam situations. Future work is to integrate the traffic prediction framework with other popular concepts of 5G such as beamforming and mm-wave technologies, to provide services to vehicular users in traffic jam.

## V. Acknowledgment

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