Power Efficient Communication Interface Selection in Cellular Vehicle to Everything Networks

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to network communication, and enables the system to select the communication interface, which can provide safe, reliable and energy efficient communication for VUEs. We study energy efficient VUE association problem, which aims to balance the power consumption of VUEs and cellular infrastructure with the help of the selection of the appropriate communication interface. The problem aims to minimize power consumption of the network for Uplink (UL) and Downlink (DL) links, by switching on/off the Small Base Stations (SBSs) and supports C-V2X link formation either over LTE-Uu conventional cellular radio interface and 5G or over Sidelink (SL), PC5 radio interface. We additionally incorporate realistic power consumption model for BSs, VUEs in UL and Fronthaul (FH) links, centralized controller and Transmit (TX) and Receive (RX) operations of VUEs. Simulation results demonstrate that enabling the selection of communication interface provides decrease in power consumption of the network instead of forcing VUEs to form communication links over LTE-Uu conventional cellular radio interface for varying number of distance thresholds and VUEs.

I. INTRODUCTION

The vision for always-connected VUE aims a safer, greener and more enjoyable driving experience, which requires new levels of connectivity such as V2X and cellular 4G/5G, and on device intelligence such as VUE-to-VUE (V2V), machine-to-machine or device-to-device communication techniques. To this purpose, C-V2X is proposed, which includes V2X communication and cellular communication [1]. C-V2X link formation is enabled either over the LTE-Uu interface, which can be unicast and/or leverage evolved multimedia broadcast multicast services whereas in the latter case, over a road-side unit/BS, which can disseminate V2X safety data towards multiple VUEs in a given area via evolved multimedia broadcast multicast services [2].

CV2X enables the VUEs to select the communication interface which can provide safe, reliable, delay tolerant and energy efficient communication for VUEs. Since network infrastructure is not involved in the data transmission in case of V2V communications, direct communication between the two ends of V2V communication helps to reduce latency efficiently [3], contributes to a higher system capacity for mobile broadband services [4] or a better power usage for massive machine type communications [5]. However, the effect of transition from LTE-Uu conventional cellular radio interface and 5G to PC5 radio interface is not investigated on total system power consumption in C2VX.

The goal of this paper is to formulate and propose efficient solution methodology for the optimization problem of energy efficient VUE association with the goal of minimizing total network power consumption by the selection of the appropriate communication interface in C2VX, while considering the accurate power consumption models, rate, capacity and effect of FH links.

- We provide a holistic framework for VUE association based on UL/DL decoupling and V2V communication incorporating dynamic on/off scheme for SBSs in a Cloud Network to minimize total power consumption. Additionally, we account for the static and dynamic power consumption of MBS, static power consumption of SBS, power consumption of FH links as a function of data rate, power consumption of VUEs in UL and power consumption of V2V communication links for the first time in the literature.
- We incorporate mmWave physical layer characteristics in which we restrict the number of simultaneous transmissions by the number of RF chains by taking the advantage of massive MIMO.
- We neglect interference due to directional transmission in 5G systems.
- We illustrate the superiority of the V2V communication in a Cloud Network to traditional network in terms of minimizing total power consumption for different distance threshold values and for different number of VUEs via extensive simulations. We also demonstrate that for decoupled UL/DL VUE association and V2V communication scheme, VUEs form V2V communication links rather than utilizing cellular communication, for specific distance threshold values and for increasing number of VUEs, which further minimizes total power consumption.

The rest of the paper is organized as follows. Section II describes the system model and the assumptions used throughout the paper. The joint optimization of UE association, switching on/off the SBSs and V2V communication link formation with the objective of minimizing the system power consumption has been formulated in Section III. Simulations and Performance Evaluation are presented in Section IV. Finally concluding remarks are given in Section V.
II. SYSTEM MODEL

- In our model, MBS provides C-Plane, carrying control signalling, cell specific reference signals, resource allocation and traffic processing, for the whole architecture. MBS operates at LTE cellular frequencies and is equipped with $N_{RF,M}$ RF chains. Within the coverage of MBS, there are $K$ SBSs containing $N_{RF,S}$ RF chains and operating at mmWave frequencies. SBSs are mainly used to provide high speed data transmission with D-Plane, which carries actual user traffic and executes traffic processing to satisfy QoS (without C-Plane), in hotspots. Additionally, there are $N_v$ VUEs with velocity $\bar{V}$ that request connection within the coverage of SBS with single antennas. Each VUE can be served by one BS in DL and in UL or by one VUE in SL. Therefore, UE demand is not splittable. Lastly, dynamic on/off transition of SBSs is analyzed according to DL to UL switch periodicity [6] at a certain time instant.

- The channel estimation is done based on Channel State Information Reference Signal transmitted from MBS and SBSs [10]. The attenuation levels from MBS and SBS $S$ to VUE $j$ are denoted by $\alpha_{ij}^{M}$ and $\alpha_{ij}^{S}$ at time $t$, respectively. The attenuation levels from VUE $j$ to MBS and SBS $S$ in UL are $\theta_{ij}^{M}$ and $\theta_{ij}^{S}$ at time $t$, respectively. Further, $\theta_{ij}^{S}$ is the attenuation level at time $t$ in SL from VUE $j$ to VUE $j'$ within coverage of SBS $S$, respectively. With the information gathered about attenuation levels, Cloud decides on the least power BSs provide different achievable rates at time $t$ in DL from MBS and SBS $S$ to VUE $j$, denoted by $R_{d,Mj}^t$ and $R_{d,Sj}^t$, respectively. The achievable rates in DL at time $t$ are formulated as [12]:

$$R_{d,ij}^t = B_i \log \left( 1 + \frac{P_{i}^{t} * \alpha_{ij}^{t}}{[N_{RF,i}] * N_0 * B_i} \right)$$  \hspace{1cm} (1)

where $i$ is M or S, $B_M$ and $B_S$ represent the transmission bandwidth for MBS and SBS $S$, respectively. $P_{i}^{t}$ indicate the transmission power of MBS and SBS $S$ at time $t$, respectively, $N_0$ is the power spectral density of the noise, interferences both in UL and in DL are ignored due to directional transmission and $\alpha_{ij}^{t}$ is the DL pathloss measured at the VUE at time $t$ based on the DL transmit power of the reference symbols. Maximum number of VUEs that can be simultaneously served by SBS $S$ and MBS at time $t$ is less than or equal to the number of RF chains $N_{RF,S}$ and $N_{RF,M}$, respectively, which is motivated by the spatial multiplexing gain of the described multi-user hybrid precoding system in [13].

- The power assignment for the transmission at the VUE at time $t$ is performed to overcome $\gamma$ fraction of the pathloss respect to a reference received power per resource block at 0 dB pathloss, $P_0$, below $P_{max}$ [14] to:

$$P_{t,UE}^{i} = \min \{P_{max}, P_0 + \gamma * \alpha_{ij}^{t} \}$$  \hspace{1cm} (2)

where $i$ is M or S.

- The achievable rates in UL $R_{u,Mj}^t$ and $R_{u,Sj}^t$ at time $t$ are formulated as in [12]:

$$R_{u,ij}^t = B_i \log \left( 1 + \frac{P_{t,UE}^{i} * \theta_{ij}^{t}}{N_{0i} * B_i} \right)$$  \hspace{1cm} (3)

where $i$ is M or S and and $B_M$ and $B_S$ represent the transmission bandwidth for MBS and SBS $S$, respectively. $N_{0M}$ and $N_{0S}$ is the power spectral density of the noise at each SBS $S$ and MBS. Since the UE has one antenna, the effect of RF chains on achievable rate of UEs is neglected.

- The achievable rate in SL at time $t$, $R_{u,jj'S}^t$, is formulated as in [12]:

$$R_{u,jj'S}^t = B_{jj'S} * \log \left( 1 + \frac{P_{t,UE}^{i} * \theta_{jj'S}^{t}}{N_{0jj'S} * B_{jj'S}} \right)$$  \hspace{1cm} (4)

where $B_{jj'S}$ is the bandwidth specified for V2X communication and $N_{0jj'S}$ is the power spectral density of noise at each VUE at time $t$ within the coverage of SBS $S$.

- $Q_{d,j}$ and $Q_{u,j}$ are demanded data rate of UE $j$ in DL and in UL at time $t$, respectively.

- The channel utilization is defined as the ratio of the demanded data rate to the data rate that can be supported over the channel. The channel utilization from MBS and SBS $S$ to UE $j$ in DL at time $t$ are denoted by $\beta_{d,Mj}^{t}$ and $\beta_{d,Sj}^{t}$, respectively, and formulated as $\beta_{d,ij}^{t} = \frac{Q_{d,j}}{R_{d,ij}^t}$, where $i$ is M or S as in [15]. On the other hand, the channel utilization from MBS and SBS $S$ to UE $j$ in UL are denoted by $\beta_{u,Mj}^{t}$ and $\beta_{u,Sj}^{t}$, respectively, and formulated as $\beta_{u,ij}^{t} = \frac{Q_{u,j}}{R_{u,ij}^t}$, where $i$ is M or S as in
Incorporating dynamic power consumption of MBS, FH link and the SBSs and V2V communication link formation with the received power consumption. Due to decoupled UL/DL transmission, the power consumption of the receiver, airconditioner and backhaul link [18]. $P_{\text{Dyn,M}}$ is formulated as $F^t \cdot P_t$, where $F^t = \sum_{j=1}^{N_{t,j,M}} \beta_{u,j,M}^t + \beta_{o,j,M}^t$ is the load factor that represents the ratio of the sum of channel utilization of the active users both in DL and UL to the total capacity of MBS in terms of RF chains at time $t$, and $P_t$ consists of power consumption of power amplifier, the transceiver, the digital signal processing unit.

Each SBS $S$ with coverage range less than 30 meters and output power around 20 dBm is assumed to consume constant power, $P_S$, across all traffic load since SBS $S$ has a limited service capacity (4 to 16 UEs) and can easily get overloaded. $P_S$ includes power consumed in microprocessor $P_{mp}$, in FPGA $P_{P,PGA}$, in transceiver $P_{tx,S}$ and in power amplifier $P_{amp,S}$ as in [16].

Due to decoupled UL/DL transmission, the power consumed on FH link in DL at time $t$ is denoted as $P_{d,fh}$ and is a linear function of the demanded data rate of UE $d,fh$ whereas the power consumed on FH link in UL at time $t$ is denoted as $P_{u,fh}$ and is a linear function of the demanded data rate of UE $j$ in UL at time $t$, $Q_{d,fh}^j$. The received power consumption $P_{Rx,j}$ of a UE $j$ at time $t$ is assumed to be constant as in [20].

The transmit power consumption of a UE $j$ at time $t$, $P_{T,X,j}$, consists of circuit power consumption $P_{\text{circuit}}$ and power consumed in the power amplifier $P_{\text{amp}}$ at time $t$. $P_{T,X,j}$ is formulated as $P_{\text{amp}} \cdot \rho$ in [21], where $\rho$ is power amplifier efficiency.

### III. Problem Formulation

The joint optimization of VUE association, switching on/off the SBSs and V2V communication link formation with the objective of minimizing the system power consumption, by incorporating dynamic power consumption of MBS, FH link power consumption, VUE power consumption due to VUE-BS links and V2V communication links given the capacity and rate constraints, is formulated as the following optimization problem:

\[
\begin{align*}
\min & \quad \sum_{t=1}^{T} \left( P_{\text{Static}} + \sum_{j=1}^{N_t} (\beta_{d,M,j}^t \cdot P_t \cdot x_{M,j}^t) + \sum_{j=1}^{N_t} \beta_{u,j,M}^t \cdot x_{M,j}^t \right) + \\
& \quad \sum_{S=1}^{K} P_S \cdot T_S^2 + \sum_{S=1}^{K} P_{h,j} \cdot \sum_{j=1}^{N_t} Q_{d,j}^t \cdot x_{S,j}^t + \\
& \quad \sum_{j=1}^{N_t} \left( P_{T,X,j}^t \cdot (1 + \beta_{d,M,j}^t) \right) \cdot y_{S,j}^t + \\
& \quad \sum_{S=1}^{K} P_{h,j} \cdot \sum_{j=1}^{N_t} Q_{d,j}^t \cdot \left( y_{S,j}^t + z_{j,S}^t \right)
\end{align*}
\]

subject to

\[
\begin{align*}
Q_{d,j}^t \cdot x_{M,j}^t & \leq R_{d,M,j}^t, j \in \{1, N_h\}, t \in \{1, T\} \\
Q_{d,j}^t \cdot x_{S,j}^t & \leq R_{d,S,j}^t, j \in \{1, N_h\}, S \in \{1, K\}, t \in \{1, T\} \\
Q_{d,j}^t \cdot y_{M,j}^t & \leq R_{d,M,j}^t, j \in \{1, N_h\}, t \in \{1, T\} \\
Q_{d,j}^t \cdot y_{S,j}^t & \leq R_{d,S,j}^t, j \in \{1, N_h\}, S \in \{1, K\}, t \in \{1, T\} \\
x_{M,j}^t + \sum_{S=1}^{K} x_{S,j}^t & = 1, j \in \{1, N_h\}, t \in \{1, T\} \\
y_{M,j}^t + \sum_{S=1}^{K} y_{S,j}^t & = 1, j \in \{1, N_h\}, t \in \{1, T\} \\
\sum_{S=1}^{K} \sum_{j=1}^{N_t} z_{j,S}^t & \leq 2, j \in \{1, N_h\}, S \in \{1, K\}, t \in \{1, T\} \\
\sum_{S=1}^{K} \sum_{j=1}^{N_t} z_{j,S}^t & \leq y_{S,j}^t, j \in \{1, N_h\}, j' \in \{1, N_h\} S \in \{1, K\}, t \in \{1, T\} \\
d_{j,j'}^t \cdot z_{j,S}^t & \leq d_{h}, j \in \{1, N_h\}, j' \in \{1, N_h\} S \in \{1, K\}, t \in \{1, T\} \\
x_{M,j}^t \leq T_S^t, j \in \{1, N_h\}, S \in \{1, K\}, t \in \{1, T\} \\
y_{M,j}^t \leq T_S^t, j \in \{1, N_h\}, S \in \{1, K\}, t \in \{1, T\} \\
z_{j,S}^t \leq T_S^t, j \in \{1, N_h\}, j' \in \{1, N_h\} S \in \{1, K\}, t \in \{1, T\} \\
\sum_{j=1}^{N_t} Q_{d,j}^t \cdot x_{S,j}^t + \sum_{j=1}^{N_t} Q_{d,j}^t \cdot y_{S,j}^t + \sum_{j=1}^{N_t} \sum_{j'=1}^{N_t} Q_{d,j}^t \cdot y_{S,j'}^t + \sum_{j=1}^{N_t} \sum_{j'=1}^{N_t} Q_{d,j}^t \cdot y_{S,j'}^t + \sum_{j=1}^{N_t} \sum_{j'=1}^{N_t} Q_{d,j}^t \cdot y_{S,j'}^t & \leq C_{h,j}^t, S \in \{1, K\} t \in \{1, T\} \\
\sum_{j=1}^{N_t} \beta_{u,s,j}^t \cdot x_{S,j}^t + \sum_{j=1}^{N_t} \beta_{u,j}^t \cdot y_{S,j}^t & + \\
\sum_{j=1}^{N_t} \sum_{j'=1}^{N_t} \beta_{u,s,j'}^t \cdot y_{S,j'}^t & \leq N_{RF,S}^t, S \in \{1, K\} t \in \{1, T\} \\
\sum_{j=1}^{N_t} \beta_{u,s,j}^t \cdot x_{M,j}^t + \sum_{j=1}^{N_t} \beta_{u,j}^t \cdot y_{M,j}^t & \leq N_{RF,M}^t, t \in \{1, T\} \\
\sum_{j=1}^{N_t} \beta_{u,s,j}^t \cdot x_{S,j}^t + \sum_{j=1}^{N_t} \beta_{u,j}^t \cdot y_{S,j}^t & \leq N_{RF,S}^t, S \in \{1, K\} t \in \{1, T\} \\
\sum_{j=1}^{N_t} \beta_{u,s,j}^t \cdot x_{M,j}^t + \sum_{j=1}^{N_t} \beta_{u,j}^t \cdot y_{M,j}^t & \leq N_{RF,M}^t, t \in \{1, T\} \\
\end{align*}
\]

where $K$ is the number of SBSs, $N_h$ is the number of VUEs and $T$ is the total time period. The decision variables of the
problem are $T_S^t$, which is a binary variable taking value 1 when SBS $S$ turns on in case of VUE association in UL or in DL and 0 otherwise at time $t$; $x_M^t,j$ and $x_S^t,j$, which are binary variables taking values 1 in case of association of VUE $j$ to MBS and VUE $j$ to SBS $S$ in DL, respectively and 0 otherwise at time $t$ and $z_j^{t,t}$, which is a binary variable taking value 1 when a V2V communication link is formed between VUE $j$ and VUE $j'$ within the coverage of SBS $S$ and 0 otherwise at time $t$.

Objective of the optimization problem is minimization of total power consumption. It includes static power consumption of MBS, dynamic power consumption of MBS in DL, opening cost of SBS and FH link power consumption in UL and in DL, VUE power consumption in UL and V2V communication link power consumption in SL. Weight ($w_t$) emphasizes the contribution of VUE power consumption on the total system power consumption. Constraints (5b) and (5c) ensure that the data rate demand of VUE $j$ at time $t$ in DL should be less than or equal to the achievable rate from MBS to VUE $j$ and from SBS $S$ to VUE $j$, respectively. Constraints (5d) and (5e) ensure that the data rate demand of VUE $j$ at time $t$ should be less than or equal to the achievable rate at MBS from VUE $j$ and from SBS $S$ from VUE $j$, respectively. Constraint (5f) represents that the data rate demand of VUE $j$ in case of V2V communication link at time $t$ in SL should be less than or equal to the achievable rate at VUE $j$ within coverage of SBS $S$. Constraint (5g) assures that VUE $j$ at time $t$ can only be assigned to MBS or and SBS in DL and constraint (5h) assures that VUE $j$ at time $t$ can only be assigned to MBS, an SBS in UL. Constraint (5i) ensures that VUE $j$ can only be assigned to at most 2 VUEs within coverage of SBS $S$ at time $t$. Constraint (5j) represents VUE $j$ has a connection to SBS $S$ if a V2V link is formed between VUE $j$ and VUE $j'$ and constraint (5k) implies that to form a V2V communication link, the distance between VUE $j$ and VUE $j'$ within coverage of SBS $S$ at time $t$ cannot be greater than the distance threshold value, $d_{th}$, which refers to the distance for minimum achievable rate that can satisfy the QoS constraints of the system. Moreover, constraints (5l), (5m) and (5n) show that SBS $S$ is turned on at time $t$ if there exists an assigned VUE in DL, in UL and a V2V communication link in SL in between VUE $j$ and VUE $j'$ within coverage of SBS $S$. Constraint (5o) implies that the total data being forwarded on FH link in UL, DL and in SL at time $t$ can not exceed the total FH link capacity. Lastly, constraints (5p) and (5q) indicate that maximum number of VUEs that can be simultaneously served by a BS in UL, DL and in SL is less than or equal to the number of RF chains that belongs to SBS, $(N_{f,S})$, or to MBS, $(N_{f,M})$, respectively, which is motivated by the spatial multiplexing gain of the described multi-user hybrid precoding system in [13].

IV. PERFORMANCE EVALUATION

The goal of this section is to evaluate the performance of the optimal algorithm at different distance thresholds and network sizes for adaptive VUE TX power and maximum VUE TX power. Simulation results for power consumption with respect to distance threshold are attained based on a network topology consisting of 20 VUEs and 4 SBSs and they are positioned randomly under the coverage of MBS. Additionally, the results for power consumption with respect to increasing number of VUEs are obtained based on a network topology consisting of 4 SBSs and a distance threshold value of 3m. SBSs are randomly and uniformly located with the minimum distance of 10 meters among each other, whereas VUEs are distributed randomly and uniformly with the minimum distance of 5 meters and the maximum distance of 15 meters among each other. Simulation results are obtained and averaged based on 5000 random configurations for 1000 DL to UL switch periods by using IBM CPLEX Optimization Studio with MathWorks MATLAB.

The links are assumed to be in Line-of-Sight (LoS), where no obstacles reside between transmit and receive antennas, or in Non-Line-Of-Sight (NLoS), where partial or full obstructions exist between the transmit and receive antennas, or in outage. The dependence of the path loss on distance summarizing large scale statistics at time $t$ is modeled as

$$\alpha^{t}_{ij} = PL(d_{0}) + 10 \times \eta_j \times \log_{10} \left( \frac{d_{ij}(t)}{d_{0}} \right) + \sigma_j^{t} \text{ in DL, as}$$

$$\theta^{t}_{ij} = PL(d_{0}) + 10 \times \eta_j \times \log_{10} \left( \frac{d_{ij}(t)}{d_{0}} \right) + X_j^{t} \text{ in UL and}$$

as

$$\theta^{t}_{jj'} = PL(d_{0}) + 10 \times \eta_j \times \log_{10} \left( \frac{d_{jj'}(t)}{d_{0}} \right) + X_j^{t} \text{ in SL,}$$

where $PL(d_{0})$ is the free space path loss in dB at a reference distance $d_{0}$, $\eta_j$ is the pathloss exponent, $d_{ij}(t)$ is the distance between BS $i$ and device $j$ at time $t$, $d_{jj'}(t)$ is the distance between VUE $j$ and VUE $j'$ at time $t$ within coverage of SBS $S$ and $X_j^{t}$ represents the shadow fading factor at time $t$, which is a zero mean Gaussian random variable with $\sigma_j^{t}$ variance. The simulation parameters follow Table I and Table II.

<table>
<thead>
<tr>
<th>TABLE I: System Assumptions</th>
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<tbody>
<tr>
<td>Carrier Frequency</td>
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<tr>
<td>Bandwidth</td>
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<td>PSD of Noise at each VUE</td>
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<tr>
<td>Capacity of FH Link</td>
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<td>Velocity of a VUE</td>
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<tr>
<td>DL Data Rate Demand</td>
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<td>UL Data Rate Demand</td>
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</table>

We investigate the effect of adaptive VUE TX power and maximum VUE TX power on the system power consumption and on the VUE association patterns for increasing distance threshold between VUEs and for increasing number of VUEs.
Adaptive TX power of a VUE can be calculated by using Formulation in [14] and maximum TX Power of a VUE is stated in Table I.

Fig. 2 compares the power consumption values of optimal algorithm for adaptive VUE TX power and maximum VUE TX power for increasing distance threshold values. For increasing distance threshold, system power consumption decreases until a specific distance threshold value and by exceeding the corresponding distance threshold, system power consumption increases. Fig. 3 demonstrates the VUE association pattern for adaptive VUE TX power. Since VUEs are distributed 5-15 meters apart from each other, the VUEs are not allowed to form V2V communication links for 3m for adaptive VUE TX Power. For this reason, the VUEs select the least power consuming association pattern, which is VUE-SBS association. Then, the power consumption decreases, as the allowed distance threshold approaches to 6m, mainly due to increasing number of V2V communication links with respect to number of VUE-BS associations. Further increase in distance threshold causes increase in total system power consumption, in the number of VUE-SBS association links and causes decrease in the number of V2V communication links. On the other hand, Fig. 4 illustrates effect of the utilization of Maximum VUE TX power on the system power consumption for increasing distance threshold values. The VUEs are not allowed to form V2V communication links since the minimum distance between them is greater than the given distance threshold value. Then, for increasing distance threshold value, the number of V2V communication links increases and the number of VUE-BS pairs decreases until a specific threshold value. As the distance threshold exceeds the specific distance threshold value, the number of V2V communication links decreases and the number of VUE-BS association pairs increases. Also, the distance threshold value for the transmission with maximum VUE TX power has a higher threshold value than the value for transmission with adaptive VUE TX power because high transmit power value can satisfy QoS even in high pathloss in mmWave communication scenarios.

Fig. 5 illustrates the system power consumption of optimal algorithm for adaptive VUE TX power and maximum VUE TX power for increasing number of VUEs. For increasing number of VUEs, system power consumption values of association for adaptive VUE TX power and maximum VUE TX power increases. However, system power consumption of the VUE association with Adaptive VUE TX power outperforms system power consumption of the VUE association with maximum VUE TX power. The reason is that the increase in the number of VUEs causes increase in the total VUE power consumption. Additionally, as the number of VUEs increases, the VUEs get closer in the specified region and the probability of forming a V2V communication links increases as shown in Fig. 6 (b) and in Fig. 7 (c).

V. CONCLUSION AND DISCUSSION

In this paper, we study energy efficient VUE association problem, which aims to balance the power consumption of VUEs and cellular infrastructure with the help of the selection of the appropriate communication interface. Simulation results demonstrate that selection of V2V communication mode provides decrease in power consumption of the network instead of forcing VUEs to form communication links over LTE-Uu

<table>
<thead>
<tr>
<th>Component</th>
<th>MBS</th>
<th>SBS</th>
<th>VUE</th>
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<tbody>
<tr>
<td>Transceiver</td>
<td>100W</td>
<td>1.8W</td>
<td>100W</td>
</tr>
<tr>
<td>Power Amplifier</td>
<td>156.3W</td>
<td>2.4W</td>
<td>100W</td>
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<td>100W</td>
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<td>100W</td>
</tr>
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<td>Receiver</td>
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<td>-</td>
<td>100mW (20)</td>
</tr>
<tr>
<td>Receiver</td>
<td>-</td>
<td>-</td>
<td>100mW (20)</td>
</tr>
</tbody>
</table>

TABLE II: Internal hardware power consumption
conventional cellular radio interface for varying number of distance thresholds and VUEs. For the future work, we aim to concentrate on our proposed heuristic algorithm to solve the optimization problem in polynomial time and compare the performance of our heuristic with the previously proposed heuristic algorithms.

REFERENCES

[22] 3GPP TS 36.213: "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures".