Hybrid Cell Selection Mechanism for V2X Handover

Faiza Al Harthi and Abderezak Touzene

Abstract The integration and implementation of vehicle-to-everything (V2X) in the transportation sector can potentially improve vehicle, passenger and traffic safety, and efficiency. This benefit, which is one of the objectives of intelligent transport systems, faces challenges and difficulties parallel to those that hinder the realization of the benefits promoted by 5G mobile networks and beyond. High-speed user equipment (UE) in the form of vehicles must be able to seamlessly connect to various entities in the network while avoiding common handover (HO) issues such as frequent and unnecessary HOs and radio link failures resulting in the degradation of quality of service (QoS). In this paper, we propose a hybrid cell selection mechanism based on signal quality, coverage, and bandwidth to reduce issues and optimize operations concerning HO that will boost V2X network performance.

**Keywords** Handover · Signal strength · Coverage · Bandwidth · Hybrid algorithm

1 Introduction

A seamless user experience is the end goal of 5G networks, and for network communications to be smooth and uninterrupted, devices must be near a base station (BS) to increase signal strength and reduce interference. In the event of an unavailable BS, device-to-device (D2D) communication has been identified as the best solution for signal availability and BS proximity problems [1]. D2D is a promising component in 5G networks that enhances energy efficiency, throughput, latency, and spectrum utilization in cellular networks. This is clearly evident when it comes to the deployment of D2D use cases such as V2X where with the high velocity of UE, reliable and less frequent change connections are crucial to save people's lives [2].

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Fig. 1 V2X communication
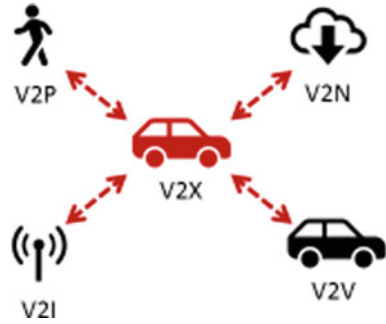
V2X communications, as shown in Fig. 1, are one of the evolving technologies that enable vehicles to connect to each other (V2V), to the road environment including pedestrians (V2P) and infrastructure (V2I), and to cellular networks (V2N). The Federal Communications Commission (FCC), in 1999, allocated a spectrum in the 5.9 GHz band for the purpose of intelligent transport services (ITSs) that resulted in extensive research for the implementation of V2X communications. In 2010, an IEEE radio standard for V2X based on 802.11p technology called dedicated short-range communication (DSRC) was released. DSRC allows communication through PC5, which is also known as Sidelink. Another type of connection is through cellular network (C-V2X). Both technologies operate in the 5.9 GHz band, although C-V2X can operate in the operator's licensed band (Uu interface). However, both technologies fail to provide the required performance when QoS in V2X applications is rigorous [3]. V2X use case requirements include speed, which can reach a maximum of 500 km/h without limitations, communication range, or latency, which shall be 100 ms between UEs in V2V/V2P/V2I deployment. These requirements characterize V2X as a high mobility use case [4].

Highly mobile UEs in a heterogeneous D2D network rely on device centric rather than a network centric approach to connectivity. It enables the UE to maintain a direct connection with other UEs with or without the presence of BS. The devices have the capability for network setup and control [5]. This is especially useful since highly mobile devices need to switch from one network to another when coverage to maintain communication fades. In order to avoid connection termination, HO mechanisms allow the active connection to be transferred from weak network coverage to another stronger cell. HOs in wireless networks can be achieved between various access technologies, operators, and cells. HO is one of the improved mechanisms that plays a vital role during communication in heterogeneous networks (HetNets). HetNets are defined by 3GPP LTE Advance standard as the paradigm to handle varied wireless coverage zones, cell sizes, and capacities. This type of network is made up of different types of small base station cells (SBS) and low-power nodes such as microcells, picocells, femtocells, and relays [6]. However, this model poses a major challenge where densification of SBS increases cell edges and inter-cellular interaction. It is estimated that small cells (SCs) can make the handover happen every 11.6 s [7]. This performance is challenged, especially in V2X use cases where UEs

are fast moving and get in and out of coverage areas. This can negatively impact V2X performance as frequent connection switching can occur. Furthermore, a solution is required that would make this type of network handle situations well through automated means. The HO challenges can be solved by having the vehicle choose the ideal cell before the handover decision. This can significantly reduce HO issues and improve the network QoS [8].

2   Related Work

Various studies have provided the basis for this research. It was mentioned in [9] that in smart solutions for handling different technology characteristics, stringent QoS requirements and advanced V2X use cases can be addressed by context awareness. In [10], the mechanism implements context awareness using the previously stored user contexts and behavioral information to predict user mobility and skip unnecessary handover process. Although, this mechanism improves the overall HO process, and it requires a type of computing platform and processing technique that caters for V2X deployment in femtocells. In [11], the study focused on V2X communications solely on macrocell and femtocell infrastructure. They proposed a BS selection scheme using Markov decision policy for V2X communication. The mechanism uses received signal strength (RSS) prediction to select a BS.

Device-to-device (D2D), which was incorporated into the 3GPP Release 12 standards as proximity services (ProSe) [12], was created with the purpose of supporting the Internet of things (IoT) in 5G networks. Article [13] studies ProSe and V2X connections using Sidelink, which streamlines D2D interactions across cellular networks. The demodulation reference signal (DMRS) uses power-normalized-correlation (PNC) to detect active peers during mobility. The distributed system monitors out of coverage (mode 2 and 4) and network-assisted communications (mode 1 and 3). In the first context, discovery periods are an Aloha-like protocol, and in the second, a polling-like protocol leveraging media access control (MAC) layer or physical collision model. Only Sidelink is evaluated for network selection. In [14], the GPS system is investigated and compared with several location algorithms. A multi-stage localization approach is proposed that makes use of neighboring UEs in order to locate a target UE in harsh channel conditions. The main challenge of this channel is that UE has poor BS localization. Using neighbor discovery, the two nearest nearby UEs are determined. Distance calculations provide two angle of arrival (AoA) alternatives for target UE. Oriented beamforming is used to differentiate the accurate AoA estimate by forming small arcs around the two AoA possibilities. Using the predicted AoA and distance to adjacent UEs, the user's position is computed. The Poisson line Cox point process for vehicle locations and planar point process for users locations is used to model vehicle location [15]. In this context, the author also determines the effective rate provided to the typical user to address the impact of vehicle broadcast on the cellular network. In this case, it is associated with the closest BS, resulting on more HO. Due to the semi-static scheduling mechanism, the random

access procedure used by UE to initiate a data transfer has a low resource efficiency. With the large access requirements of the 5G network, this problem would be exacerbated. Intelligent access channel allocation must be used to efficiently decrease resource consumption while ensuring access latency and reliability, which needs the BS to precisely predict the number of UEs conducting random access. The author [16] developed long short-term memory (LSTM) to process the time series capacity of the data, making it suited for tackling the active UE number estimate problem.

In [17], it was pointed out that implementing vertical HO allows the use of different access technologies, multiple network interfaces, multiple QoS parameters, and multiple connections that can be changed. A common approach for cell selection in mobile communication is based on the signal interference noise ratio (SNIR) or received signal strength interference (RSSI) [18]. However, implementing the HO process using the same set of user parameters in HetNets could degrade mobility and performance [19]. This is quite a challenge in V2X use cases where most UEs are fast moving and require different QoS parameters (user preferred) dictated by application requirements. Since 5G is expected to handle V2X applications, HO mechanisms that were usually developed for centralized implementations will not be suitable for the distributed and hybrid HO requirements of V2X networks [20]. To effectively implement HO between cells and handle diverse requirements in HetNets and V2X, it is crucial to achieve optimal context interpretation [10].

Cell selection in HetNets must consider a number of parameters according to network context and use cases. The selected parameters need further to be optimized [18]. This is valid in HetNets infrastructure where different SBS deployed with a variation in terms of power transmission, coverage, and number of connections are accepted. Many recent studies (see Table 1) have focused on using more than one parameter for cell selection. The cell selection methods in [10, 18, 21, 23, 25, 28] result in improvement in HO performance, however, these studies did not consider the V2X use case. Applying this method in a different topology can lead to more frequent HO. In [22], RSSI, load, and speed are used as cell selection parameters, although only RSSI is considered for handover decisions. In [26], network weight is used to assess network performance and user preferences to choose the optimal cell selection, and the hierarchy analysis method is used to assign the appropriate weight to each selection metric. Load balancing is neglected in this study. The same limitation is applicable for [27]. Overloaded cells can affect network performance, resulting in more link failures.

Overall, in the ideal design of a network, supplementing less setup cost while providing good signal strength coverage is considered an ideal deployment approach for 5G BSs [21]. Enough resources at the target cell must be reserved to ensure that the connection will not be terminated during handover [8]. Based on that, this paper considers three parameters: link quality (RSSI), coverage, and bandwidth for ensuring efficient seamless connectivity for handover. The handover decision is based on an optimization algorithm. This approach is considered to control handover issues such as frequent and unnecessary HOs and link failures.

Table 1 Link parameters

Paper	Parameters																				
	Link Quality						Speed	Direction/User trajectory/mobil	Bandwidth/Channel Capacity	Coverage/Distance	Location	Power transmission	Channel Model	Power Consumption	Power	Displacement angle	Packet Loss Rate	Transmission Delay Time	User Preference	Traffic Load	Dwell Time
	RSRP	RSSI/RSS	SINR	Propagation	Signal Intensity	Jitter															
[10]	X						X					X	X							X	
[11]		X					X	X	X												
[21]										X	X										
[18]		X								X				X							
[22]		X					X		X												
[23]								X													
[24]								X								X					
[25]									X			X									
[26]									X			X					X	X			
[27]					X				X						X		X	X	X		
[28]			X						X												
[29]		X																			X

3 Hybrid Cell Selection Method

V2X communications can be enhanced by selecting the best BSs based on QoS metrics and/or UE preferences. It was pointed out in [30] that prior to network selection, information about BSs should be gathered based on context and user preferences. The selected BS information is processed and stored in the UE buffer for HO use, which would lessen the need for centralized BS processing and best serve the UE preference according to current context, application requirements, or presence of

vertical networks. A periodic update of the stored selected BS information is based on operational levels of the required parameters [31]. Figure 2 illustrates the overall research flow by pre-processing and segmenting the handover mechanism to provide seamless connectivity based on the ideal selection of BS using signal quality, cell coverage, and bandwidth as the parameters and hybrid algorithm. Phase II and Phase III calculation are restricted to the output of Phase I.

These phases can be explained as follows:

Radio signal strength can be affected by many obstructions while propagating from transmitter to receiver. This can cause signal attenuation and affect the network performance. Even though radio frequency is developed with the ability to penetrate surfaces, the signal strength is degraded while moving across reinforced concrete in walls or changing in the weather. Moreover, the interference that happens between two waves is considered a killer for signal communication. To ensure the availability of the network, the vehicle must choose the best signal quality among the signals.

Coverage measures how broad an area around a wireless transmitter has sufficient signal strength for wireless devices. The findings are used by vehicles to associate with the best coverage BS that allows them to travel for long distances without the need for changing the connection. In many studies, the long distance is measured based on the velocity of the vehicle. A macrocell is used for the association of a high velocity vehicle. Middle and low vehicle speeds are associated with small cells, and in V2X, these are referred to as femtocells. However, in this study, connections are not segregated based on the level of speed. For instance, the term 'long distance' here means the coverage area.

The number of connected UEs is increased in HetNets. SCs in HetNets have different power transmission and link capacity. At certain times, the SC may reach its maximum capacity, which results in link failure. Therefore, bandwidth estimation is needed before the selection of a BS for handover. If the number of users is more in the BS, the bandwidth will be reduced. To calculate the number of connections, the researcher must monitor the BS interface which is carrying different types of packets. For instance, the source vehicle can understand the average bandwidth of the BS which is available for transferring the connection.

The entire system model shown in Fig. 3 is converted into a connected graph. The aforementioned parameters, link quality, coverage, and bandwidth are used for the selection of the context-based BS. The author has introduced an optimization algorithm to select the best BS among the other BSs which helps to reduce the
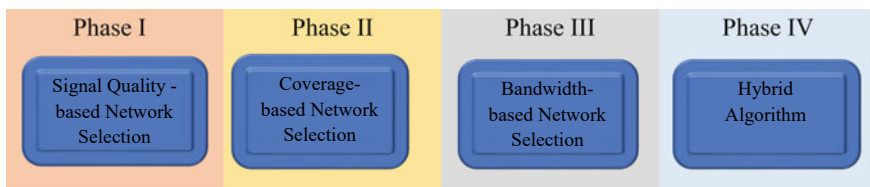

Phase I	Phase II	Phase III	Phase IV
Signal Quality - based Network Selection	Coverage- based Network Selection	Bandwidth- based Network Selection	Hybrid Algorithm

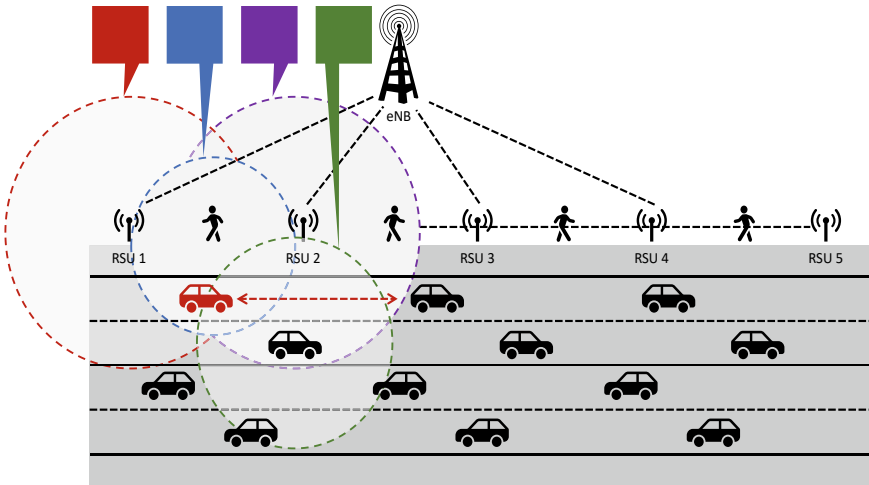**Fig. 2** Overall research workflow

Fig. 3 BS selection model

number of HOs and latency and increase signal quality to V2X. Moreover, this algorithm provides an acyclic graph to eliminate loops between BSs.

3.1 System Model

The system model, as shown in Fig. 3, consists of a number of vehicles, pedestrians, road side units (RUSs), and a macrocell that represents V2X communications. It can be used in any small cells such as Wi-Fi, WiMax, and WLANs which are using different transmission power and coverage areas. There are four overlapping cells (C1, C2, C3, and C4) within the area of the red car (source vehicle) that may require different parameters. The source vehicle moves forward at a random speed. The macrocell (gNB) has a link connection with RSUs through Uu interfaces. A link connection can exist between the RSUs and vehicles of different use cases (V2V, V2I, V2P, and V2N) using PC5 Sidelink interface.

3.2 Signal Quality-Based Network Selection

Figure 4 depicts a simplified handover situation in which the source vehicle is linked to RSU1 and is driving toward the coverage zone of RSU2, pedestrian (P), and adjacent vehicle (AV) which are considered base stations. The source vehicle continuously monitors the signal strength of these BSs (RSU2, P, and AV) with the purpose of storing the BSs with the best signal quality (illustrated in signal strength algorithm).
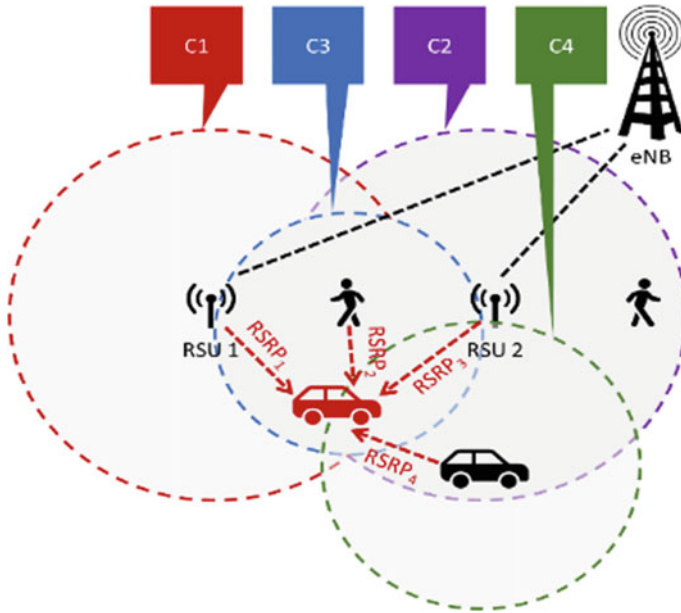
Fig. 4 Signal quality-based tower selection

If the detected signal strength of the V2P in the intersection region exceeds that of the RSU1, and the V2P can establish the connection to provide the resources required by the source vehicle, a cell selection of V2P will be considered as the best for the handover process based on the signal quality referred to in Table 2.

The surrounding environment and the maximum radius of the cell, both of which have a significant influence on the received signal, are two of the most crucial elements that determine wireless coverage. The received signal characteristics are primarily influenced by three factors: multipath fading, shadow fading, and path loss propagation. Although signal to interference and noise ratio (SINR) is a signal quality metric, it is not specified in 3GPP specifications and so is not provided to the network. The carrier received signal strength indicator RSSI indicates the average overall received power measured where RSRPn and RSRPs are the RSRPs of the neighboring and

Table 2 Signal quality [32]

RF signal condition	RSRP (dBm)	RSRQ (dBm)	SINR (dBm)
Excellent	$> = -80$	$> = -10$	$> = 20$
Good	-80 to -90	-10 to -15	13 to 20
Medium	-90 to -100	-15 to -20	0 to 13
Weak	$< = -100$	< -20	$< = 0$

serving BSs, respectively. The serving cell's offset is A3 offsets, and the cell individual offset between adjacent and serving cells is the cell individual offset between the neighboring and serving cells (CIOn, s). In this situation, however, the RSRP of the serving cell—a femtocell in this case—drops below the threshold or the RSRP of neighboring cells only when the vehicle is inside the area of coverage [25].

RSRP1 is a serving cell that is connected to the source vehicle, as indicated in Fig. 3. Due to its movement, the source vehicle discovered three more signals from different BS: RSRP2, RSRP3, and RSRP4. With the formula below (1), the car will choose the best signal quality among these signals. All received signals containing BS information are recorded in the vehicle's buffer, which will be utilized in catastrophe scenarios.

$$RSRPn - RSRPs > A3offsets - CIOn, s \text{ or } RSRPn >= RSRPs \qquad (1)$$

where

RSRPs   Signal from source (serving) BS
RSRPn   Signal from neighboring BS
A3 offsets   Offset of the serving cell
CIOn, s Cell individual offset between the neighboring and serving cells.

The received signal strength indicator (RSSI) is a metric that indicates the overall received wide-band power in all symbols, including all thermal and interference noise. RSSI is not reported by vehicle to BS since it can be estimated from reference signal received quality (RSRQ) and RSRP reported by UE.

$$RSSI = Serving \, cell \, power + interference \, power + noise.$$

Reference signal received power (RSRP) is a variation of RSSI.

$$RSRP(dBm) = RSSI(dBm) - 10 \times \log (12 \times N).$$
$$Reference \, signal \, received \, quality(RSRQ) = RSRP/(RSSI/N).$$

where

- $N =$ Number of physical resource blocks (PRBs).
- RSSI = Noise + serving cell power + interference power during reference signal (RS) symbol.
- RSRQ depends on serving cell power and the number of Tx antennas.

Signal Quality Algorithm

Step 1: Keep decoding BSs (cells) DMRS (PSBCH, PSCCH, PSSCH) by measuring transmission power.
Step 2: Vehicle must collect all sensing information of reserved resources and RSSI/RSRP measurements.

Step 3: The vehicle must exclude its connection from the common resource block (CBR) and make its available resource set.

Step 4: Select the Tx based with reliable BS based on the best signal strength.

Step 5: Sort the collected BS information according to signal quality from highest to lowest (BS ranking based on the current parameter).

Step 6: Select the top 50% BSs and store the information in the UE's buffer.

Step 7: Update the BS information in the buffer after T-time by collecting new BS information (Step 2) then proceeding to Step 4 to ensure the reliability of buffer information.

Step 8: If the number of BSs in the buffer is 0, reselection is triggered; go to Step 2.

3.3 Coverage-Based Network Selection

The source vehicle has to select best coverage BS based on large coverage area, which is calculated based on the height of the antenna and transmitter power. Furthermore, as shown in Fig. 3, the source car is getting signals from four different RSUs (RSU1, RSU2), pedestrian, and adjacent car. Out of four coverage intersections, RSU2 is providing more coverage to the source. The source vehicle can travel up to (D1) distance at (T1) time without need of handover. This maintains the connection for a long period. Once it reaches the radius of the coverage, it has to initiate the HO discovery process.

Coverage Area Calculation:

The antenna's height 'h' is located at point 'S' on the surface. 'O' is the center of the antenna, and 'Re' is the radius of the place. Let 'P' be the point on the place at a distance of 'd' from 'S'. Beyond the 'S', the device cannot receive the signal from the transmitter 'T'. Point TP is tangent of the place, hence the height of the tower $SP = PT = d.PT = d$ as shown in Fig. 5.

$\Delta\ OPT$ is right tringle. As per Pythagoras theorem, $OT^2 = OP^2 + PT^2$

Therefore, $(Re + h)^2 = Re^2 + d^2$

$Re^2 + 2\ Re\ h + h^2 = Re^2 + d^2$

Therefore, $d^2 = 2\ Re\ h + h^2$

Hence, 'h' is a small value compared to the radius of the earth, so h^2 can be removed.

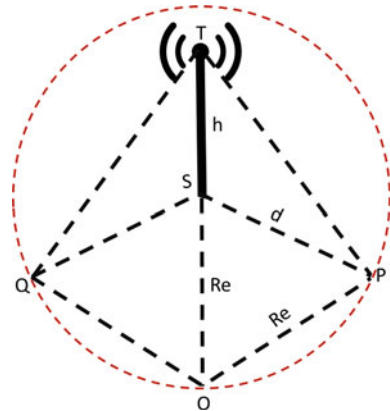$d^2 = 2\ Re\ h$.

Therefore, $d = \sqrt{2hRe}$

Coverage area is calculated as $A = \pi d^2$

Time Calculation

$$\text{Time} = \text{Distance}/\text{Speed}$$
$$S = \{BS_1, BS_2, BS_3, \ldots, BS_n\}$$

Fig. 5 Coverage area calculation

$$\forall d, t \in \text{BS}$$

where BS is base station, $D1$—maximum distance and $T1$—minimum time

If the source vehicle is traveling toward the destination, it has to change the BS frequently. To avoid the number of HOs, the source vehicle has to calculate and prepare the neighbor BSs distance ($D1$) and reaching time ($T1$) to prepare the HO process. The local decision is made in the vehicle based on the stored value in the queue of the vehicle's buffer. Based on the highest ($D1$) value and minimum ($T1$) value, the source vehicle has to choose maximum coverage BS for changing the HO using BS ($D1, T1$).

Coverage Algorithm

Step 1: Set of available BSs will be based on the selected BSs from the link quality algorithm.

Step 2: Calculate coverage area of BSs based on the '$D1$' and '$T1$'.

Step 3: $D1$ and $T1$ values are stored in the buffer for selecting BSs.

Step 4: Sort the collected BS information according to $D1$ and $T1$ values from highest to lowest (BS ranking based on the current parameter).

Step 5: Select the top 50% BSs and store the information in the UE's buffer.

Step 6: Update the BS information in the buffer after T-time by collecting new BS information (Step 2) to ensure the reliability of buffer information.

Step 7: If the number of BSs in the buffer is 0, reselection is triggered, go to Step 2.

3.4 Bandwidth-Based Network Selection

The researcher recommends counting the number of vehicle connections utilized on PC5 and Uu interfaces to determine the number of user connections at a certain cell

or BS. This technique may provide assured bandwidth to each vehicle while avoiding congested network connections.

We make the following assumptions:

- Measure the number of users connected in the BS interface from time to time.
- To arrange BSs in the queue based on the available users and bandwidth.
- The best BS has to be selected from the above queue for HO.

Bandwidth calculation based on V2X interfaces is shown in Fig. 6.

To calculate the bandwidth need required, the following formula can be used:

(Application throughput)   ×   (Number of concurrent users)   = Aggregate application throughput

BS = {Number of users, time).
$S = \{BS_1, BS_2, BS_3,...., m\}$.
Bk(t) provided bandwidth of BS, $k \in$ BS at time t,
Set of vehicles $U = \{1,2,3, ..., n\}$.
Bi(t) is the bandwidth needed for user, $i \in U$ at time t,
Ai is a selected BS by the user i.

Bandwidth Algorithm

Step 1: Set of available BSs will be based on the selected BSs from link quality algorithm.
Step 2: Determine the number of users currently connected in each BSs.
Step 3: Select best BSs with minimum number of users.
Step 4: Sort the collected BS information from lowest to highest users (BS ranking based on the current parameter).
Step 5: Select the top 50% BSs and store the information in the UE's buffer.
Step 6: Update the BS information in the buffer after T-time by collecting new BS information (Step 2) to ensure the reliability of buffer information.
Step 7: If the number of BSs in the buffer is 0, reselection is triggered; go to Step 2.

Fig. 6 Bandwidth calculation based on V2X interfaces
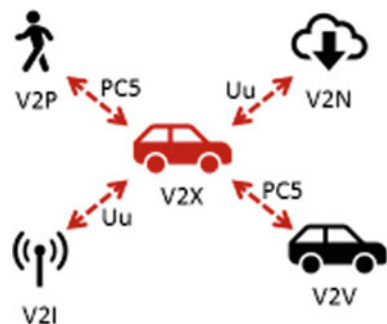
3.5 Hybrid Cell Selection Algorithm

Each vehicle has an option to select a BS based on the signal quality, coverage, and number of users strategies mentioned earlier. The elimination of BSs that do not pass the required specifications has already lessened the possibility of HO issues. An optimization technique is introduced based on the above three parameters to identify BS for HO.

Step 1: A vehicle must call the best result of signal quality, coverage, and bandwidth algorithms.

Step 2: Predict a vehicle's movement by searching through historical records stored in a table.

Condition 1: If a vehicle record is found, select the BSs that the vehicle will probably encounter in the trajectory. Proceed to Step 3.

Condition 2: If no historical record is found, proceed to Step 4.

Step 3: Any BS identified in Step 2, Condition 1 can be immediately used by the vehicle for HO, eliminating the need to HO to other BSs.

Condition 1: If there is a change in the selected value (signal quality, coverage, or bandwidth) in the currently used BS, other BSs can be evaluated for the next HO.

Condition 2: If the vehicle has existing connection history in the BSs, HO preparation and authentication can be ignored.

Condition 3: If no BSs are available in the current trajectory, proceed to Step 1.

Step 4: Compare signal > St, coverage > Ct and bandwidth > Bt for each BS.

Step 5: Apply an optimization algorithm.

Step 6: Arrange in buffer.

Step 7: Select optimized BS for HO then save this information in a history table.

Step 8: If BS < = St or Ct or Bt.

Step 9: Go to Step 5 to select the next best option or else go to Step 1.

where

Ct   Coverage threshold value,
St   Signal threshold value and,
Bt   Bandwidth threshold value.

4   Conclusion

Handover in HetNets has gained a lot of importance, especially with the emergence of 5G and 6G networks. This process presents a more challenging scenario in V2X due to the high mobility nature of vehicles. Although 5G has extended its coverage, by creating D2D communications, this can lead to a greater number of the HOs during the UE mobility that greatly affects network performance. This paper proposes a new approach to reduce issues affecting HO operations by the selection of best BSs using methods that rely on signal quality, coverage area calculations, and bandwidth

parameters. Furthermore, the author has proposed a new optimized algorithm using the above-mentioned parameters to select the best cell for optimal handover decision making. In future work, the proposed mechanism will be extensively evaluated using a simulation tool.

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