

Wi-Fi offloading between LTE and WLAN with combined UE and BS information

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Abstract With the increasing popularity of mobile devices, cellular networks are suffering the consequences of a mobile data traffic explosion. Operators and standard development organizations have adopted Heterogeneous Network (HetNet) solutions which offload traffic from cellular networks to other Radio Access Technologies to reduce the overloaded situation. To minimize service blocking ratios, HetNets need to be designed with an efficient approach to allocate heterogeneous channel resources. This work proposes a Combined UE and BS Information scheme (CUBI), which follows the standard architecture proposed by 3rd generation partnership project. We compare the impacts of using the User Equipment (UE) information only, and Base Stations (BS) information only to achieve network selection. We then propose a 2-round solution that benefits from both UE and BS information. The UE-information scheme is based on channel qualities of all available networks, and using it selects the network which provides the highest data rate. On the other hand, the BS-information scheme (BSI) is based on traffic loads of all UEs to allocate bandwidth, and

using BSI will prevent BSs from overload situations. The simulation results demonstrate that CUBI can decrease service blocking ratios by 26 and 8.9 %, compared to schemes separately using US and BS information, respectively.

Keywords LTE · WLAN · Heterogeneous Networks · Network selection · Vertical handoff

1 Introduction

With the increasing popularity of mobile devices, cellular networks suffer explored mobile data traffic [1, 2]. For example, AT&T [3] experienced a 5000 % increment of mobile data traffic over the past 3 years. Most UEs tend to connect to a limited number of BSs so that insufficient bandwidth cannot satisfy the service demands of the UEs. To deal with this situation, 3GPP proposes a traffic offloading solution which utilizes small cells [4] to share high traffic loads. Although the small-cell solution can offload traffic loads and increase data rates, it still suffers from insufficient bandwidth and interference problems because it uses the same frequency band as macro cells. Bandwidth efficiency could be low if there is no accurate interference avoidance and cancellation between small and macro cells. Another way to increase bandwidth and enhance data rates is to use HetNet [5], as for example, Wireless Local Area Networks (WLANs). 3GPP RAN2 (Radio Access Network) discusses the interworking between WLAN and the access networks in 3GPP. The major advantage of HetNets is it uses distinct frequency bands for different RATs. In this way, the capacity can be enlarged because WLANs can provide extra bandwidth and high data rates over short transmission distances.

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Traffic offloading using HetNets poses several challenges [6]. The first is to equip a notification mechanism to exchange information of traffic loads and available bandwidth between different HetNets. However, each RAT applies its own specific protocol and cannot communicate with the other RATs, and a notification mechanism is thus necessary to integrate and coordinate the RATs. The second challenge is to satisfy the service demands of UEs after handovers. When the bandwidth of the targeted HetNet is not enough to accommodate the service demand of a newly arrived UE, a user might suffer poor user experiences. A trivial method might result in not only low network utilization but also network bottlenecks [7]. As a result, a network selection methodology should consider both service demands and available bandwidth for HetNet handovers.

1.1 Separated information versus combined information

Many researches have devoted time to network selection methods [7–9], which consider UE and BS information separately. When a network selection method considers only UE information, such as channel quality, the service demands of a UE may not be satisfied if the BS encounters an overloaded situation. On the other hand, considering merely BS information, such as traffic loads, a network selection method might cause low bandwidth utilization because non-ideal data rates as a result of poor channel qualities between the UE and BS waste bandwidth.

This work presents a network selection solution that combines the UE and BS information for LTE and WLAN systems. The proposed method, called Combined UE and BS Information (CUBI) scheme, combines the UE information, i.e. Channel Quality Indicator (CQI), and the BS information, i.e. traffic loads and available bandwidth, and assigns UEs to BSs to reduce service blocking ratios and thus enhance aggregate throughput. Moreover, CUBI follows the network architecture for Wi-Fi offloading specified in TS 23.203 [10] as well as referring to the QoS Class Identifier (QCI) of LTE to identify service demands and required bandwidth. Without loss of generality, we simulate separated information schemes, i.e. UEI and BSI, as well as CUBI on NS-3 to evaluate their performance including service blocking ratios and aggregate throughput.

The remainder of this work is organized as follows. In Sect. 2 we introduce 3GPP HetNet architecture and related works. We deal with CUBI, including the notification mechanism and network selection algorithms in Sect. 3. The simulation results are presented in Sect. 4, and we conclude this work in Sect. 5.

2 Background and related works

Figure 1 shows the 3GPP HetNet architecture specified in TS23.402 [11]. For predicting the targeted network to improve system performance, the key parameters, such as channel quality indicators and service demands in LTE, are shown.

2.1 3GPP HetNet solution

The description of integrated non-3GPP IP access and LTE networks is specified in TS 23.402. As shown in Fig. 1, non-3GPP IP access can be divided into two categories, i.e. trusted and untrusted non-3GPP IP access. Trusted non-3GPP IP access immediately connects to the Packet Data Network (PDN) Gateway for data-plane transmissions, and communicates with Policy and Charging Rules Function (PCRF) for control-plane Quality of Service (QoS) policies. To integrate non-3GPP IP access with LTE networks, the 3GPP Authentication, Authorization, and Accounting (AAA) server manages user information for both of non-3GPP IP access and LTE networks. On the other hand, a secure tunnel between untrusted non-3GPP IP access and enhanced Packet Data Gateway (ePDG) protects data delivery from non-3GPP IP access to LTE networks. Similar to trusted non-3GPP IP access, untrusted non-3GPP IP access follows the QoS policies managed by PCRF to manage the required service demand of each traffic flow.

To satisfy service demands of traffic flows, the QoS levels in non-3GPP IP access should be maintained as those admitted in LTE networks. The QCIs defined by 3GPP are specified in Table 1. Resource types are categorized as Guaranteed Bit Rate (GBR) and non-GBR. The corresponding criteria of packet delay and packet losses are defined as well. Considering the inter-RAT handover to non-3GPP IP access, whether the targeted non-3GPP IP access can offer high data rates and sufficient bandwidth to satisfy the service demands should be examined. However, data rates are highly affected by channel conditions while bandwidth is determined by the amount of the overall traffic load. Considering only the channel condition corresponding to each BS seen by the UE may omit the congestion issue with regard to the BS. On the other hand, making the handover decision only according to the traffic loads passing through the BS may result in low bandwidth utilization because of poor channel conditions.

2.2 Related works

A number of researchers have investigated vertical handovers from cellular networks to HetNets. Three categories, including mechanism design, decision algorithm

Fig. 1 Architecture within 3GPP access and non-3GPP access

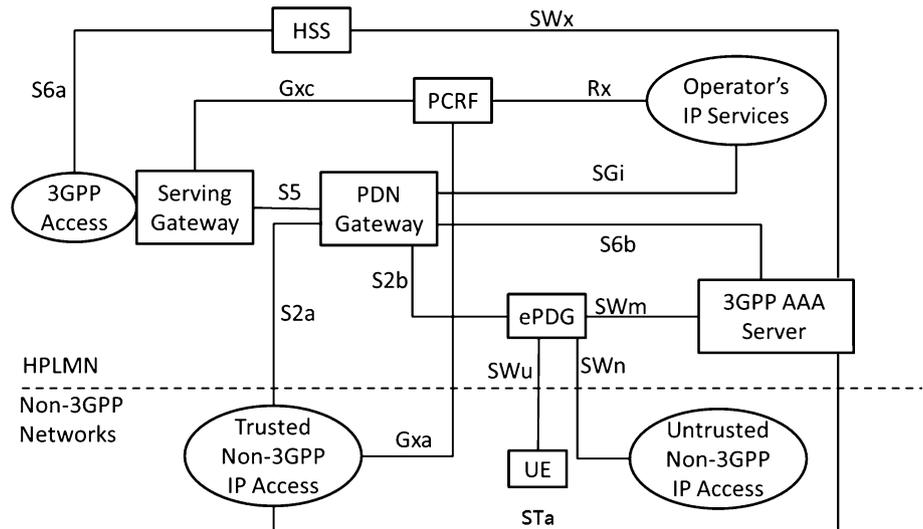


Table 1 LTE QoS class identifier characteristics

QCI	Resource type	Priority	Packet delay (ms)	Packet loss	Example
1	GBR	2	100	10^{-2}	Conversational voice
2		4	150	10^{-3}	Conversational video (live streaming)
3		3	50	10^{-3}	Real time gaming
4		5	300	10^{-6}	Non-conversational video (buffered streaming)
5	Non-GBR	1	100	10^{-6}	IMS signaling
6		6	300	10^{-6}	Video (buffered streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
7		7	100	10^{-3}	Voice, video (live streaming) interactive gaming
8		8	300	10^{-6}	Video (buffered streaming) TCP-based (e.g., www, email, chat, ftp, p2p file sharing, progressive video, etc.)
9		9			

design, and both of these, are introduced. Always Best Connected (ABC) [6] designed mechanisms over multi-RAT environments to optimize user experiences. To make a vertical handover decision, Policy-based VHO [7] considered handover cost function optimization, as well as the QoS factors and channel conditions between each UE and the potential targeted networks. Handoff Necessity Estimation (HNE) [8] estimated the unnecessary handover probability to reduce handover failures based on the traveling time estimation and time threshold calculation. A PN-based approach [9] predicted the signal strength to perform handover based on location, speed, and required processing time. On the other hand, Common Radio Resource Management and Generic Link Layer (CRRM and GLL) [12] dealt with the resource control issue. However, the research considered only separated information to make handover decisions. Low data rates and insufficient bandwidth might still occur so

that service demands cannot be satisfied. To improve system performance in vertical handovers between Het-Nets, considering combined UE and BS, information is necessary to minimize service blocking ratios and enhance aggregate throughput.

3 Combined UE and BS Information (CUBI)

This work combines UE information, such as channel quality between each BS and itself, as well as BS information, like overall traffic loads, to perform vertical handovers. The proposed approach, called Combined UE and BS Information (CUBI), jointly considers UE and BS information to improve aggregate throughput and service blocking ratios. In this section, the algorithm is detailed after the terminologies and assumptions are defined, followed by an example to illustrate CUBI.

3.1 Terminology and assumptions

We assume that each UE supports the dual-mode wireless access for WLAN and LTE as well as requesting exactly one traffic flow for network service. Moreover, the service demand is accepted when available bandwidth is sufficient. The term BS is defined as a base station which includes an evolved Node B (eNB) and a Wi-Fi AP (Access Point). CUBI can handle network selection among BSs, that is, a combination of eNBs and Wi-Fi APs. Nevertheless, this work considers the scenario that multiple Wi-Fi APs are located in the coverage of a single eNB for heterogeneous network selections because eNB deployment is well-planned in cellular networks while Wi-Fi APs apply random deployment. First, certain parameters, such as QCI and service demand, are known by both UE and BS. For other parameters, a UE is aware of the CQI corresponding to each BS in the UE's receiver range, while a BS knows the overall traffic load generated by all the UEs connected to the BS. CUBI subsequently calculates the system performance based on the above parameters to match UEs and BSs. Finally, each UE connects to an assigned BS.

Without loss of generality, the notations and terminologies are specified in Table 2. Given N UEs and $M + 1$ BSs consisting of exactly one eNB and multiple Wi-Fi APs in the network system, each UE is numbered as $UE_i, 1 \leq i \leq N$, while the eNB and Wi-Fi APs are numbered as BS_0 and $BS_j, 0 < j \leq M$, respectively. Further, the system parameters are classified into three categories: UE-specific, BS-specific, and common. In the common category, the admitted service demand and the CQI is known by both the UE and BS. That is, where $\forall UE_i, 1 \leq i \leq N, \forall BS_j, 0 \leq j \leq M$, (1) UE_i is connected to BS_j ; (2) there is a corresponding service demand SD_i and the channel quality indicator $CQI_{i,j}$ known by both UE_i and BS_j . Next, the UE-specific category includes the CQIs between all the BSs and the UE. In another words, where $\forall UE_i, 1 \leq i \leq N, \forall BS_j, 0 \leq j \leq M, j \neq j'$, there is a corresponding channel quality indicator $CQI_{i,j}$ which is known by UE_i but unknown by $BS_{j'}$, except the serving $BS_{j'}$. Finally, in the BS-specific category, each BS is aware of the available bandwidth and the overall traffic loads.

$\forall BS_j, 0 \leq j \leq M$, BW_j is the available bandwidth and TL_j is the summed traffic loads from all the UEs connecting to BS_j .

According to the above definitions, an approach using only UE-information could choose the BS whose CQI is the highest. On the other hand, an approach using only BS-information could avoid assigning a UE with a high service demand to a BS with insufficient bandwidth. As a result, service blocking may result from either UE_i encounters too poor $CQI_{i,j}$ to achieve the acceptable data rates, or BS_j does not have enough BW_j to accommodate SD_i . To improve service blocking ratios and aggregate throughput, the main idea of CUBI is to utilize Combined UE and BS Information to assign UEs to BSs.

The problem statement is as follows. Given N UEs and $M + 1$ BSs, each UE_i has service demand SD_i and knows $CQI_{i,j}$ corresponding to each BS_j , while each BS_j is aware of BW_j and TL_j . CUBI collects the information on UEs and BSs, and then applies a two-round model to utilize the information to match UEs and BSs. Eventually, CUBI aims at minimizing service blocking ratios and enhance aggregate throughput.

3.2 Notification mechanisms

To collect information related to inter-RAT handovers, an integrated notification mechanism is necessary to exchange metrics, such as channel qualities and traffic loads. For traffic offloading between HetNets, at least two kinds of notification mechanisms for exchanging loading information and channel qualities are necessary. First, a UE cannot be aware of traffic loads of BSs, but a BS can notify UEs whether it is overloaded or not. One way to notify a UE of the overloading status is as follows. When a UE sends a service request to establish a dedicated bearer in LTE systems, the BS could reject the dedicated bearer request because of insufficient bandwidth. The UE would then know that the eNB may suffer from an overload situation. Figure 2 shows the causes of the dedicated EPS bearer context reject. For Wi-Fi systems, no standardized mechanism can be utilized so that this work uses our proprietary mechanism.

Table 2 Description of terminologies and notations

Categories	Notation	Descriptions
Common	$\{SD_i 1 \leq i \leq N\}$ $\{CQI_{i,j} 1 \leq i \leq N, 0 \leq j \leq M, BS_j \text{ is the serving BS for } UE_i\}$	Service demand of UE_i Channel quality indicator between UE_i and the serving BS_j
UE-specific	$\{CQI_{i,j} 1 \leq i \leq N, 0 \leq j \leq M, BS_j \text{ is not the serving BS for } UE_i\}$	Channel quality indicator between UE_i and all the BS_j , except the serving BS
BS-specific	$\{BW_j 0 \leq j \leq M\}$ $\{TL_j 0 \leq j \leq M\}$	Available bandwidth of BS_j Overall traffic loads of the UEs connecting BS_j

- #26: insufficient resources;
 #31: request rejected, unspecified;
 #41: semantic error in the TFT operation;
 #42: syntactical error in the TFT operation;
 #43: invalid EPS bearer identity;
 #44: semantic error(s) in packet filter(s);
 #45: syntactical error(s) in packet filter(s); or
 #95 – 111: protocol errors.

Fig. 2 Dedicated EPS bearer context reject cause value [17]

The second mechanism is channel quality indicator reporting. In LTE systems, a UE has to periodically report channel quality to determine an MCS (modulation and coding scheme). A higher MCS value corresponds to a higher data rate. In WLAN systems, reporting channel quality is also needed to determine an adaptive MCS, but report timing is not standardized. For example, the Automatic Rate Fallback (ARF) rate control algorithm [13] uses a packet-based timer to trigger reporting.

This work designs a middleware for the notification mechanism. A feature of middleware is the ability to hide the heterogeneity between individual systems. In LTE systems, an eNB uses the S1 interface to communicate with the EPC, and the X2 interface to communicate with the other eNBs. The main idea of middleware design is to enhance the S1 and X2 interfaces as the S1 plus and X2 plus interfaces which translate HetNet messages to LTE-based message. For HetNets, for example Wi-Fi, an AP can use the middleware to emulate the QoS policy in IEEE 802.11e [14] to a dedicated bearer. The access categories defined in IEEE 802.11e specify different priorities for different traffic types. This work relates the access category in IEEE 802.11e to each QCI. The AC_VO and AC_VI are corresponding to the QCI 1–3 and QCI 4, respectively. For non-GBR traffic, the AC_BE is corresponding to the QCI 6–7 while the AC_BK is corresponding to the QCI 8–9. Wi-Fi AP can also use middleware to transform RSSI (Receiver Signal Strength Indication) into CQI. Figure 3 shows the schematic diagram of middleware design.

3.3 Network selection algorithms

The optimal network selection for vertical handovers has been defined as an NP-Hard problem in [15]. The traffic flow corresponds to the service in this work. The required QoS and resources for each UE_i correspond to SD_i and $CQI_{i,j}$ with the serving BS_j . Moreover, the communication resources defined in [15] correspond to BW_j of BS_j in this work. According to the mapping, the network selection problem in HetNets is a complex problem mapped to an NP-Hard problem. To avoid the complexity of solving a

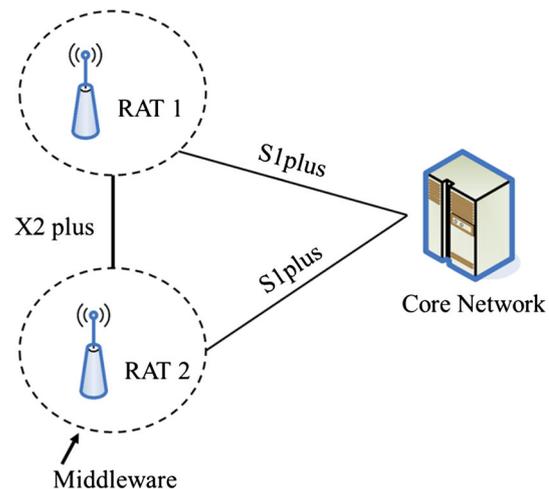


Fig. 3 Schematic diagram of middleware

NP-Hard problem, this work proposes a heuristic approach to making the network selection in order to minimize service blocking ratios and enhance aggregate throughput.

3.4 UE-information approach

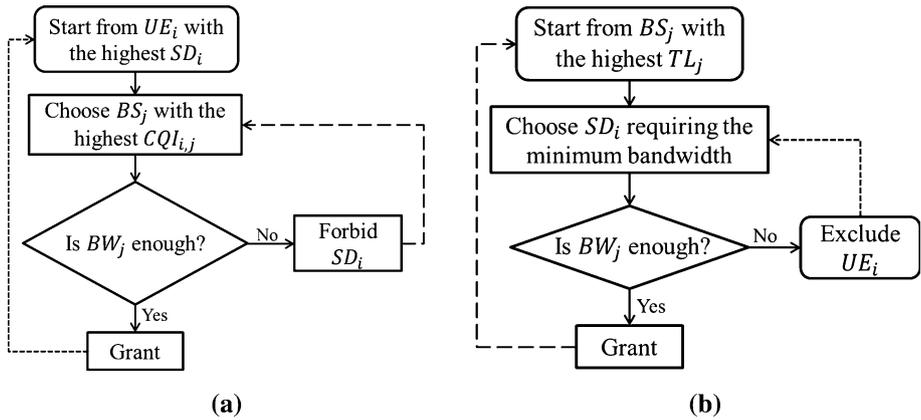
To compare the separated-information and combined-information approaches, the decision approaches, called UE-information (UEI) and BS-information (BSI), which use only the one-side information are discussed as well. For all these approaches, the algorithm is triggered when a newly arriving UE wants to join the network, or a connected UE is forced to do the handover to retain the service quality. For UEI, UE_i with the highest SD_i has the highest priority to choose a BS to deal with its service. Then BS_j with the highest $CQI_{i,j}$ would be chosen to enhance the data rate. However, the situation might occur where most of UEs connect to the same BS whose signal strength is high. As a result, each BS has to forbid the service requests when insufficient bandwidth appears. Figure 4a shows the flow chart of the UEI approach. Initially, UE_i with the highest SD_i sorts the BSs based on their CQI and then chooses the BS_j with the highest $CQI_{i,j}$ to connect to. When BS_j receives service demand SD_i ,

BS_j examines its BW_j to determine whether SD_i can be admitted or not. If not, BS_j forbids SD_i and then UE_i chooses another BS. Otherwise, SD_i is admitted. All UEs repeat the same procedure to choose a BS.

3.5 BS-information approach

The other separated-information approach is BSI. BS_j with the highest TL_j firstly chooses a UE to avoid overloading. Thus, BS_j chooses UE_i with SD_i that requires the minimum bandwidth. Nevertheless, a BS_j cannot perceive whether

Fig. 4 Flow chart of the separated information approaches. **a** UEI, **b** BSI



$CQI_{i,j}$ is the best choice for UE_i . If not, the consumed bandwidth may not be the minimum in the context of the whole system. The worse CQI the UE and BS suffer, the more bandwidth the transmission consumes as a result of the low data rate. Thus, UE_i may have a better BS to connect to so that the consumed bandwidth become reduced for the same SD_i . In Fig. 4b, BS_j with the highest TL_j sorts the UEs according to the required bandwidth of their service demands. If BW_j is insufficient, BS_j excludes UE_i and chooses another UE. Otherwise, SD_i is admitted and then another BS can choose a UE from those remaining.

3.6 Combined UE and BS Information (CUBI)

The advantage of using UE information is that UE_i can connect to BS_j with the highest $CQI_{i,j}$. On the other hand, the advantage of using BS information is that the BS_j can assess the required bandwidth of SD_i to prevent BS_j from overloaded situations. To benefit from both, CUBI utilizes the Combined UE and BS Information to match UEs and BSs for obtaining low service blocking ratios and high aggregate throughput. CUBI applies a two-round model to utilize the combined information to match

UEs and BSs, as shown in Fig. 5. In round 1, the CQI between each UE_i and each BS is reported to BS_j whose $CQI_{i,j}$ is the highest. CUBI utilizes the LTE measurement report function existing in the standards to collect the CQI corresponding to each BS. After receiving the report, BS_j chooses UE_i with SD_i that requires the minimum bandwidth and then checks whether there is sufficient BW_j or not. If not, BS_j would pass the report to the BS with the second high CQI corresponding to UE_i through the S1 or X2 interface to perform the decision procedure above. When all the UEs are assigned to the BSs or rejected by all the BSs, round 2 finishes.

3.7 An example of network selection algorithms

An example of the network selection algorithms is illustrated as follows. Table 3a shows the configurations of $CQI_{i,j}$, and TL_j , respectively. For UEI, UE_i would sort all the BSs based on CQI and choose BS_j with the highest $CQI_{i,j}$. In the example, UE_1 , UE_2 , UE_3 , UE_4 , and UE_5 choose BS_1 , BS_0 , BS_0 , BS_1 , and BS_2 , respectively. From UE_1 to UE_5 , each UE tries to request the corresponding BS for its service demand in turn. The upper bound of TL_j that each BS_j can drive is 10. After UE_1 and UE_2 obtains their service demands, TL_0 and TL_1 become 9/10 and 5/10, respectively. Because BS_0 is saturated, UE_3 can never connect to BS_0 . Thus, UE_3 considers a handover to BS_1 which has the second highest $CQI_{3,1}$. UE_4 consequently

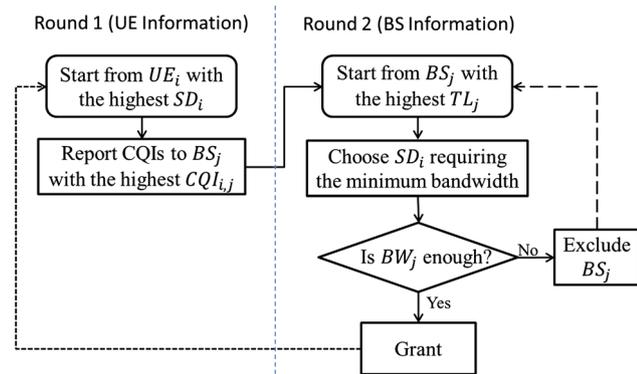


Fig. 5 Flow chart of CUBI

Table 3 An example of $CQI_{i,j}$ and TL_j corresponding to UE_i and BS_j

$CQI_{i,j}$ (Required BW)	BS_0	BS_1	BS_2
UE_1	3 (7)	8 (2)	5 (5)
UE_2	9 (1)	5 (5)	4 (6)
UE_3	8 (2)	7 (3)	4 (6)
UE_4	2 (8)	6 (4)	1 (9)
UE_5	2 (8)	1 (9)	8 (2)
TL_j	8/10	3/10	2/10

Table 4 The results of the network selection algorithms in the Example

UEI/BSI/CUBI ↘	BS_0	BS_1	BS_2
UE_1	x/x/x	O/O/O	x/x/x
UE_2	O/O/O	x/x/x	x/x/x
UE_3	x/x/x	O/O/x	x/x/O
UE_4	x/x/x	x/x/O	x/x/x
UE_5	x/x/x	x/x/x	O/O/O

suffers the situation where there is no targeted network that can satisfy its service demand. The service request of UE_4 would be rejected. Finally, UE_5 connects to BS_2 . Another illustration for BSI is as follows. Considering TL_j , each BS_j selects the UE with the minimum required bandwidth to serve. First of all, BS_0 selects UE_2 while BS_1 selects UE_1 and UE_3 . However, UE_4 would be left without a serving BS due to insufficient bandwidth after BS_2 selects UE_5 .

To resolve the service blocking situations above, CUBI requests each UE_i to report its CQI list to BS_j with the highest $CQI_{i,j}$. As illustrated by the example, UE_1, UE_2, UE_3, UE_4 , and UE_5 report to BS_1, BS_0, BS_0, BS_1 , and BS_2 , respectively. First, BS_0 selects UE_2 and then pass the CQI list of UE_3 to BS_1 because TL_0 has been overloaded. Next, BS_1 selects UE_1 and UE_4 and passes the CQI list of UE_3 to BS_2 again as a result of overloading. Finally, BS_2 selects UE_3 after BS_2 selects UE_5 and still has enough bandwidth. Table 4 summarizes the results.

4 Simulation

In this section, we specify the simulation environment and scenarios. The configurations are detailed and the simulation results are discussed.

4.1 Simulation setup

We develop the proposed CUBI in the NS-3 simulator [16]. The NS-3 has already supported the LTE and Wi-Fi

models, which are used to integrate our environments. Then we set up the positions of UEs with the mobility model. We control each UE to request an application service, e.g. VoIP, video streaming, FTP, etc. One-third UEs issue each type of the services to observe the impacts of service blocking ratios. In view of the simulation scenarios, six Wi-Fi APs with non-overlapping coverage are located in the coverage of the eNB. Each UE has at most two targeted networks, i.e. one Wi-Fi AP and the eNB, at once. Without loss of generality, additional Wi-Fi APs are randomly deployed in the coverage of the eNB to discuss the service blocking ratios under different number of Wi-Fi APs. The number of targeted networks for each UE would become unfixed. The simulation configurations of the two scenarios are summarized in Table 5. The radio parameters of LTE and Wi-Fi are specified.

4.2 Simulation results

To evaluate the effectiveness of the proposed solutions, we discuss the performance in three cases: (1) separated information versus combined information; (2) different numbers of UEs; and (3) different numbers of Wi-Fi APs.

4.3 Separated information versus combined information

To investigate the relationships between the number of UEs and service blocking ratios with separated and combined information, three applications are used to observe their service blocking ratios. Figure 6 shows the simulation results. For UEI, the significantly high service blocking ratios result from that most UEs connect to the BS with the highest CQI. The service blocking ratios increase when the bandwidth is exhausted. On the other hand, BSI suffers from high service blocking ratios when certain UEs are chosen by the BSs with the non-ideal CQIs in view of the UEs. As the number of UEs increases, the service blocking ratios of UEI applications increase quickly because each UE still attempts to connect to the BS which has spent a lot

Table 5 Simulation configuration

Parameter	Value
eNB downlink bandwidth	5 MHz
Wi-Fi standard	802.11a
Number of UEs	30–150
Number of APs	6, 10–30
Number of eNBs	1
MAC scheduler	Round-Robin
VoIP	G.711; 64 Kbps; 160 Bytes payload; QCI = 1
Video streaming	MPEG-4; Peak/Mean Bit Rate = 2.1/0.1 Mbps; QCI = 4
FTP	2 Mbps; QCI = 8

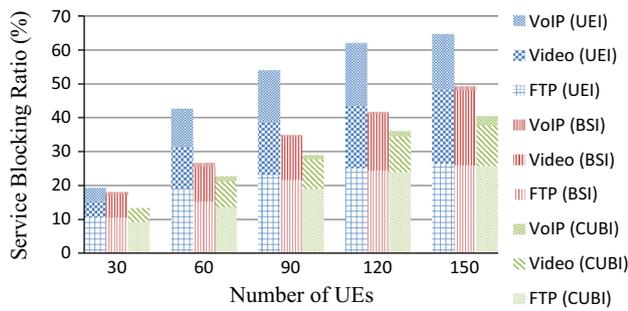


Fig. 6 Separated information versus combined information

of bandwidth to satisfy the other UEs. However, no additional bandwidth is provided to accommodate increasing UEs. By contrast, the CUBI can accommodate a large number of the UEs which intend to connect to the BS with the highest CQI because the BS may pass the request to the second candidate BS when it becomes overloaded. CUBI sacrifices the UEs which have low CQIs against the BSs. To find out the extreme differences, the summed service blocking ratios of the three applications are 36 % for CUBI and 62 % for UEI when the number of UEs is equal to 120. On the other hand, the summed service blocking ratios of CUBI and BSI are 40.4 and 49.3 % when the number of UEs is equal to 150, respectively. In another words, CUBI decreases the service blocking ratios by 26 and 8.9 %, compared to UEI and BSI, respectively.

4.4 Different numbers of UEs

Figure 7 shows the results of the service blocking ratios under different numbers of UEs. When the number of UEs is equal to 30, the service blocking ratios of the three schemes which are from 13.3 to 19.3 % appears likely equal. The reason is that the overall traffic load is unsaturated and most of the service demands can still be handled by each BS. As the number of UEs increases, the overall traffic load increases and certain overloaded BSs could not satisfy the service

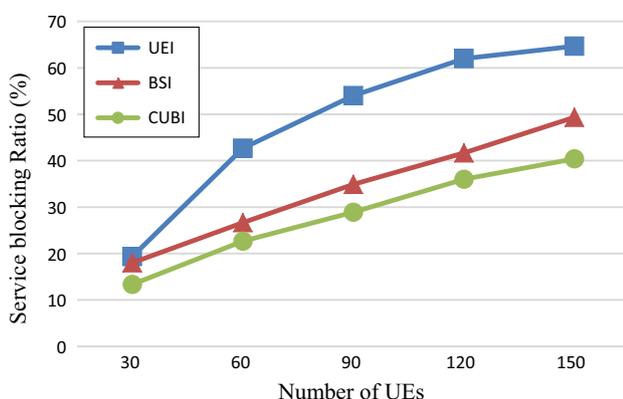


Fig. 7 Service blocking ratios under different numbers of UEs

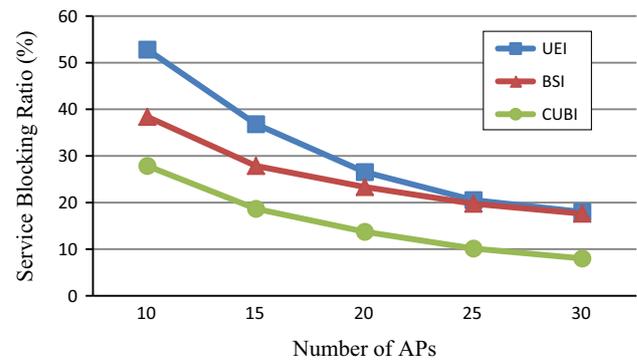


Fig. 8 Service blocking ratio under different numbers of Wi-Fi APs

demands. Because UEI does not consider the loading of BSs and trivially choose the BS with the highest CQI, a bottleneck might occur at the BSs that a large number of UEs connect to. The service blocking ratio of UEI quickly increases to 64.7 % when the number of UEs is equal to 150. Compared to CUBI and BSI, the differences of service blocking ratio are 24.3 and 8.9 %, respectively.

4.5 Different numbers of Wi-Fi APs

In Fig. 8, the service blocking ratios of the three schemes are distributed in a wide range when the number of Wi-Fi APs is fewer than 20. UEI, BSI, and CUBI suffer at most 52.8, 38.4, and 27.9 % of service blocking ratio when the number of Wi-Fi APs is equal to 10. The reason is that the total bandwidth of the BS and Wi-Fi APs is insufficient to accommodate the overall traffic load generated by all the UEs. UEI suffers the BS-overloaded situation as a result of many of connections from the UEs in a dense area. Although BSI considers the required bandwidth for the service demands, BSI wastes bandwidth because of low channel qualities. As the number of Wi-Fi APs increases, the bandwidth is never a bottleneck so that the service blocking ratios became close. When the number of Wi-Fi APs is equal to 30, UEI and BSI perform the same in service blocking ratio. Because CUBI applies a two-round approach to pass service demands to another BS when the bandwidth of a BS is insufficient, CUBI utilizes the whole bandwidth and has the lowest service blocking ratio among the three schemes.

5 Conclusion

HetNet is one way of solving current mobile data traffic dilemmas. Although 3GPP proposes the HetNet architecture, HetNet still needs to design a network selection approach to avoid overload situations. To achieve low service blocking ratios and satisfy service demands, we propose two approaches using separated UE and BS

information, and one combined UE and BS approach. UEI only considers the channel quality between a single UE and the corresponding BSs. On the other hand, BSI considers the overall traffic load of a BS. However, only considering UE or BS information is insufficient and increases service blocking ratios.

In this work, we show the advantage of using combined information, and design a 2-round solution, called CUBI. The main idea of CUBI benefits from the two types of separated information. In the first round, channel qualities are reported by UEs, while bandwidth allocation is made by BSs in the second round. The results show that CUBI can reduce 26 and 8.9 % service blocking ratios compared with UEI and BSI in simulation. When the Wi-Fi capacity is larger than the total traffic, the performance of UEI and BSI is almost the same because the network bandwidth is never a bottleneck. However, when the number of UEs increases, the service blocking ratios of UEI rises faster than with other approaches. CUBI holds a lower service blocking ratio than the others because the two-round approach considers channel qualities to avoid wasting bandwidth as well as sharing traffic loads with other BSs to prevent overloading.

Further issues of traffic offloading deserve future works. More information for network selection, such as application-specific demand, service policy, and data price, requires comprehensive discussions. Moreover, practical evaluations of the proposed notification mechanism and network selection algorithm are needed for standards compliance, for instance, the handoff latency between LTE and Wi-Fi.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent Informed consent was obtained from all individual participants included in the study.

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