Dynamic Inter-RAT Handover Decision for Offloading Heavy Traffic in Heterogeneous Networks

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***Abstract*—We present a dynamic inter-RAT handover decision mechanism that allocates network resource for UEs over heterogeneous cells considering UE's mobility, QoS, and cell transition for overload situations. It aims to minimize access failure and handover signalling, while prioritizing UEs with high QoS level for differentiated cell selection. We formulate the problem of dynamic cell selection over a period of time into an optimization problem consisting of step-wise binary integer programs according to UE's moving speed.**

Simulation results show that our dynamic scheme achieves low access failure ratio in a highly overloaded network. More importantly, the proposed algorithm remarkably diminishes cell handover rate by 20% compared to a counterpart algorithm based on static optimization. We demonstrate that our algorithm successfully controls cell acceptance and connected cell types by prioritizing with UE's QoS and moving speed.

I. INTRODUCTION

As wireless handheld devices have embedded a variety of radio access interfaces such as LTE, 3G, Wi-Fi, and NFC, Heterogeneous Network (HetNet) has recently attracted significant attention. In the HetNet environment, interoperation among different networks and inter-Radio Access Technology (RAT) handover are critical issues since they severely affect system performance.

Due to explosive growth in smartphone users, network service providers have been looking for diverse techniques such as data offloading and access class barring in call admission control and congestion control. For example, data offloading is one of the most practical solutions by installing small cells (e.g., femtocell, picocell, Wi-Fi access point) near home, office, and store on-the-fly. Hence, heavy data traffic from numerous user equipments (UEs) can be rerouted to small cells, alleviating overload burden at macrocells.

In 3GPP heterogeneous networks, radio resource management (RRM) algorithms should efficiently control the distribution of resources with respect to 1) cell coverage, 2) cell capacity, and 3) quality of service (QoS).

For efficient resource usage with respect to cell coverage, there have been research works on interference coordination [14] and inter-RAT handover (vertical handover) decision [7]. To address the challenge of interfering heterogeneous cells each other, the serving cells coordinate their resource allocation with the potential interferers through power control [3], [13], time-domain non-overlapping [10], and frequency-domain orthogonalization [9], enhancing network capacity. On the other hand, the inter-RAT handover schemes calculate utility functions based on Received Signal Strength Indicator (RSSI), bandwidth, and QoS [4], [17] and make a stable handover decision by switching into the specific RAT with the highest utility [16].

Fig. 1. Dynamic cell selection problem for data offloading in heterogeneous networks of a macrocell, femtocells, and Wi-Fi APs under an overload situation.

Regarding resource allocation research on cell capacity, radio resource allocation of heterogeneous cells to which UEs connect has been studied in [12]. As a network-centric approach, the network operator side wants to optimize its bandwidth through effective resource allocation to heterogeneous cells. In [15], by formulating allocation, underutilization, and rejection into a utility function with stochastic linear programming (SLP), it aims to maximize allocation in all heterogeneous networks, while minimizing the penalty of underutilization and rejection. Recently, [8] presents a static cell selection and resource allocation mechanism in heterogeneous cell overloaded networks. By considering the current available cell load status at nearby accessible cells, it finds the optimal cell selection for UEs, significantly mitigating access failure.

However, a rigorous optimization approach of inter-RAT handover decision considering all the aspects of cell coverage,

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cell capacity, and QoS has not been well explored. Further, previous works do not explicitly take into account the degree of UEs' mobility and dynamic decisions over a period of time as optimization factors.

In this paper, we present a *dynamic* inter-RAT handover decision mechanism for offloading heavy traffic in heterogeneous networks. We formulate cell coverage, cell capacity, and QoS as well as UEs' mobility into a step-wise optimization problem of binary integer programs. By prioritizing mobile UEs with high mobility to be connected to a cell with a broader cell range, we aim to achieve a relatively stable connection without incurring unnecessary handovers. Also, UEs with high QoS level are prioritized to be admitted to an available accessible cell for differentiated services. To reduce unnecessary ping-pong effects, we impose the reward of maintaining the same cell as long as the cell keeps a good connection with UE. In this way, we can significantly reduce cell transition rate, while achieving low access failure in the overload situation.

II. SYSTEM MODEL

This paper considers the problem of dynamic inter-RAT handover decision over a period of time in a heterogeneous network of a macrocell, femtocells, and Wi-Fi access points. We focus on mobile data offloading in cell overload situations where a very large number of UEs roam over the network and attempt to establish their packet-switched (PS) call connections as illustrated in Fig. 1. The objective of our proposed mechanism is to minimize access failure rate by fully utilizing available RAT cells. At the same time, the mechanism aims to prevent a ping-pong effect between cells that leads to considerable handover signalling overhead. In this work, UEs with high QoS level need to be prioritized for differentiated services.

We assume that UEs receive remaining power information of accessible femtocells from the CPICH frame (Common PIlot CHannel) and that of accessible Wi-Fi APs from the beacon signal. When each UE has received all the remaining power information from all accessible femtocells and Wi-Fi APs, it reports them to its governing macrocell by sending the Measurement Report frame in 3GPP specifications.

The governing macrocell is provided with moving speed, data QoS, accessible cell candidates, and their cell load status of UEs within the macrocell's coverage. The inter-RAT handover problem can then be described as finding a decision of *which* UE to be connected to *which* cell.

III. DYNAMIC HANDOVER DECISION

In a cell overloaded situation, a static optimization approach of heterogeneous cell selection for concurrently accessing UEs can significantly reduce network access failure [8]. Although the approach can fully optimize cell selection at each selection round, it may suffer from a critical ping-pong effect that leads to considerable handover signalling.

We present a *dynamic* inter-RAT handover decision mechanism in an overload situation. The proposed mechanism takes into account various real-world design challenges of moving UEs with varying speed, signalling overhead due to cell handover, and QoS of data that a UE wants to deliver if connected.

A. Procedure

For a governing macrocell to make inter-RAT handover decisions, it collects accessible cell types and remaining power information for all the UEs within the coverage with the following procedure.

First, each UE collects accessible cell information in the CPICH frame from nearby femtocells and in the beacon frame from nearby Wi-Fi APs. Femtocells append their own cell ID, type, remaining power level in the CPICH frame and send it to UEs. Similarly, Wi-Fi APs append their own cell ID, type, remaining power level in the beacon frame and send it to UEs.

Second, when UEs receive accessible cell and its power information, they report them to the governing macrocell through sending a Measurement Report frame.

Third, given accessible cell load status of each UE within the range, the macrocell conducts dynamic handover decisions for the UEs. The dynamic optimization procedure is described in Sec. III-B.

Finally, the macrocell initiates handover signalling procedures for UEs of which the cell selection has been transitioned, respectively.

B. Dynamic Optimization

In 3GPP, the handover decision is based on signal strength of Reference signals (i.e., RSRP – Reference Signal Received Power) from neighboring cells at UEs. If a UE receives the Reference signal from a neighboring cell that is sufficiently stronger than that from the current serving cell, that neighboring cell is selected as the UE's new serving cell. In this approach, however, the cell selection depends on signal strength information of nearby cells locally at each UE. The resulting handover decision cannot be a globally efficient solution particularly in overloaded heterogeneous networks. Note that we will call this approach as *Local* scheme in evaluation (Sec. IV).

We consider cell selection scenarios in the overloaded heterogeneous networks under a dynamic environment of moving UEs. Mobile UEs with high mobility would rather be connected to a cell with a broader cell range, e.g., macrocell since otherwise, cell selection needs to be transitioned continuously as the UE roams over the network. This frequent cell transition requires drastic handover signalling. This implies that depending on UE's moving speed, the selection of connectable cell types should be adapted. For example, UEs with low mobility can be connected to a smaller range, e.g., Wi-Fi because it would keep a relatively stable connection compared to UEs with high mobility.

Our approach also differentiates UEs according to their data QoS type. It would be best to accommodate all the UEs in the network, but if the network is not able to accept some UEs in the overload situation, we may want those UEs to be ones with low QoS levels. We provide a different priority level for cell selection according to UE's QoS level.

To minimize unnecessary cell transitions, our algorithm aims to keep connecting to the current serving cell as far as the UE is accessible within the range of the cell. This consideration contributes to designing a *dynamic* optimization with minimal cell changes, preventing high cost from handover signalling.

Putting all the above aspects together, we formulate the problem of a dynamic handover decision into a step-wise optimization problem with binary integer programs. The proposed algorithm finds the optimal connection list of moving UEs and their connected cells. It aims to minimize access failure and handover signalling overhead, while taking into account QoS requirement. The governing macrocell (or a computer cluster connected to it) executes this optimization algorithm and conducts necessary handover procedures thereafter.

To formulate the binary integer programs, we define indicator functions $I_i^{(T)}$ denoting whether cell T is selected for UE i where cell T belongs to a set of all possible cells in the network, i.e., $T \in \{C^{(M)}, C^{(F_1)}, C^{(F_2)}, \ldots, C^{(F_L)}, C^{(W_1)}, C^{(W_2)}, \ldots, C^{(W_P)}\}$. We use $C^{(M)}$ to denote the governing macrocell, and $C^{(F_j)}$ denotes one of L femtocells where $1 \leq j \leq L$, while $C^{(W_k)}$ denotes one of P Wi-Fi APs where $1 \leq k \leq P$.

Additionally, we introduce other indicator functions: 1) J_i denoting whether UE i is eventually connected to one of cells and 2) $\lambda_i^{(T)}$ indicating whether the new cell selected for UE i is the same as the previous cell.

We categorize UEs into three groups with respect to the UE's moving speed and solve an optimization problem for each category as follows.

1) Step 1 – macrocell selection for UEs with high mobility: First, our algorithm begins a macrocell selection procedure for UEs with high mobility. We list up all the UEs of which the moving speed is larger than v_{th1}. $S_1^{(M)}$ denotes a set of the UEs with high mobility.

Basically, our goal is to maximize the number of UEs with successful connections to any cell, i.e., $\sum_{i \in S_1^{(M)}} J_i$. To give some priority such that highly mobile UEs would be connected to the macrocell M, we put a weight gain of moving speed v_i for each UE i.

To favor UEs with high QoS requirement, we apply the *regularization* technique [2] by a factor of β. Also, since we aim to keep connecting the current serving cell to UE i as far as it can, our objective function includes the corresponding term by a factor of α.

Using a form of regularization is to maximize the weighted sum of the objectives: 1) the number of connected UEs with some priority of moving speed, 2) the sum of QoS values for the connected UEs, and 3) the net number of connecting UEs without cell transitions.

$$\text{maximize} \quad \sum_{i \in S_1^{(M)}} J_i \cdot v_i + \beta \sum_{i \in S_1^{(M)}} Q_i \cdot I_i^{(M)} + \alpha \sum_{i \in S_1^{(M)}} \lambda_i^{(M)} \qquad (1)$$

$$\text{subject to} \quad \sum_{i \in S_1^{(M)}} p_{UE_i}^{(M)} \cdot I_i^{(M)} \leq P_{rem}^{(M)} \qquad (2)$$

$$\sum_{T \in N_{1i}} I_i^{(T)} = J_i \leq 1 \qquad \forall i \qquad (3)$$

$$|I_i^{(M)} - \widetilde{I}_i^{(M)}| \leq 1 - \lambda_i^{(M)} \qquad \forall i \qquad (4)$$

where v_i is moving speed of UE i, Q_i is QoS of UE i ranging from 1 to 8, $p_{UE_i}^{(M)}$ is the amount of power allocated at macrocell M for UE i, and $P_{rem}^{(M)}$ is the remaining power at macrocell M. N_{1i} is a set of all connectable cells at UE i (in this step, T = macrocell M), and $\widetilde{I}_i^{(M)}$ is the previous indicator function result for UE i and macrocell M, indicating whether UE i was connected to macrocell M.

Constraint (2) ensures that macrocell M has enough power to allocate for connected UEs. Constraint (3) enforces that any UE should be connected to at most one cell. Lastly, constraint (4) encourages each UE to be connected to the previous cell as far as it can: if the cell becomes unchanged, $\lambda_i^{(M)}$ is free to have any value between 0 and 1. Hence, solutions would be determined in such a way that $\lambda_i^{(M)}$ should be 1 if possible. Otherwise, $\lambda_i^{(M)}$ is enforced to be 0.

2) Step 2 – macrocell & femtocell selection for UEs with medium mobility: After executing the first step optimization, we broaden the cell type into femtocells beyond the macrocell. In this step, we conduct cell selection for UEs that satisfied the v_{th1} threshold, but failed to be allocated to the macrocell from Step 1 and for UEs of which the moving speed is larger than v_{th2} where $v_{th1} > v_{th2}$. We denote $S_2^{(T)}$ as a set of these UEs that can access cell T where $T \in \{C^{(M)}, C^{(F_1)}, C^{(F_2)}, \ldots, C^{(F_L)}\}$.

We formulate a binary integer program similar to the one in Step 1, while adding femtocell-related terms as follows:

$$\text{maximize} \quad \sum_{i \in S_2^{(M)}} J_i \cdot v_i + \beta \cdot Q_i \left(\sum_{i \in S_2^{(M)}} I_i^{(M)} + \sum_{j=1, i \in S_2^{(F_j)}}^{L} I_i^{(F_j)} \right) + \alpha \left(\sum_{i \in S_2^{(M)}} \lambda_i^{(M)} + \sum_{j=1, i \in S_2^{(F_j)}}^{L} \lambda_i^{(F_j)} \right) \qquad (5)$$

$$\text{subject to} \quad \sum_{i \in S_2^{(M)}} p_{UE_i}^{(M)} \cdot I_i^{(M)} \leq P_{rem}^{(M)} \qquad (6)$$

$$\sum_{i \in S_2^{(F_1)}} p_{UE_i}^{(F_1)} \cdot I_i^{(F_1)} \leq P_{rem}^{(F_1)} \qquad \cdots \qquad (7)$$

$$\sum_{i \in S_2^{(F_L)}} p_{UE_i}^{(F_L)} \cdot I_i^{(F_L)} \leq P_{rem}^{(F_L)} \qquad (8)$$

$$\sum_{T \in N_{2i}} I_i^{(T)} = J_i \leq 1 \qquad \forall i \qquad (9)$$

$$|I_i^{(M)} - \widetilde{I}_i^{(M)}| \leq 1 - \lambda_i^{(M)} \qquad \forall i \qquad (10)$$

$$|I_i^{(F_1)} - \widetilde{I}_i^{(F_1)}| \leq 1 - \lambda_i^{(F_1)} \qquad \forall i \qquad (11)$$

$$\cdots$$

$$|I_i^{(F_L)} - \widetilde{I}_i^{(F_L)}| \leq 1 - \lambda_i^{(F_L)} \qquad \forall i \qquad (12)$$

where v_i is moving speed of UE i, Q_i is QoS of UE i ranging from 1 to 8, $p_{UE_i}^{(T)}$ is the amount of power allocated at cell T for UE i, and $P_{rem}^{(T)}$ is the remaining power at cell T. N_{2i} is a set of all connectable cells at UE i, and $\widetilde{I}_i^{(T)}$ is the previous indicator function result for UE i and cell T, indicating whether UE i was connected to cell T.

Constraint (6) $\sim$ (8) ensures that macrocell and femtocells have enough power to allocate for connected UEs. Constraint (9) enforces that any UE should be connected to at most one cell. Lastly, constraint (10) $\sim$ (12) encourages each UE to be connected to the previous cell as far as it can: if the cell becomes unchanged, $\lambda_i^{(T)}$ is free to have any value between 0 and 1. Hence, solutions would be determined in such a way that $\lambda_i^{(T)}$ should be 1 if possible. Otherwise, $\lambda_i^{(T)}$ is enforced to be 0.

3) Step 3 – macrocell, femtocell, and Wi-Fi AP selection for the rest of UEs: As the last step, for the rest of UEs that have not been connected to macrocell and femtocells yet in both Step 1 and Step 2, our algorithm finishes its last optimization over all possible cells of macrocell, femtocells, and Wi-Fi APs. It should be noted that in this step, we do not put the weight gain of moving speed since all of cells are under consideration. Thus, the most dominant part in the objective function (Eq. 5) is the total number of all connected UEs.

We prioritize the Wi-Fi AP cell selection for this group of UEs with low mobility by introducing the factor of γ (> 1). In addition, we consider the factor of QoS and the reward of maintaining a connection to the same cell as done in Step 1 and Step 2. We denote $S_3^{(T)}$ as a set of all the rest of UEs that can access cell T where $T \in \{C^{(M)}, C^{(F_1)}, C^{(F_2)}, \ldots, C^{(F_L)}, C^{(W_1)}, C^{(W_2)}, \ldots, C^{(W_P)}\}$.

$$\begin{aligned}
\text{maximize} \quad & \sum_{i\in S_3^{(M)}} J_i + \beta\cdot Q_i \,\Big(\sum_{i\in S_3^{(M)}} I_i^{(M)} + \sum_{j=1,i\in S_3^{(F_j)}}^{L} I_i^{(F_j)} \\
& + \gamma \sum_{k=1,i\in S_3^{(W_k)}}^{P} I_i^{(W_k)} \Big) + \alpha \,\Big(\sum_{i\in S_3^{(M)}} \lambda_i^{(M)} \\
& + \sum_{j=1,i\in S_3^{(F_j)}}^{L} \lambda_i^{(F_j)} + \sum_{k=1,i\in S_3^{(W_k)}}^{P} \lambda_i^{(W_k)} \Big) & (13)\\
\text{subject to} \quad & \sum_{i\in S_3^{(M)}} p_{UE_i}^{(M)} \cdot I_i^{(M)} \le P_{rem}^{(M)} & (14)\\
& \sum_{i\in S_3^{(F_1)}} p_{UE_i}^{(F_1)} \cdot I_i^{(F_1)} \le P_{rem}^{(F_1)} \qquad \cdots & (15)\\
& \sum_{i\in S_3^{(F_L)}} p_{UE_i}^{(F_L)} \cdot I_i^{(F_L)} \le P_{rem}^{(F_L)} & (16)\\
& \sum_{i\in S_3^{(W_1)}} p_{UE_i}^{(W_1)} \cdot I_i^{(W_1)} \le P_{rem}^{(W_1)} \qquad \cdots & (17)\\
& \sum_{i\in S_3^{(W_P)}} p_{UE}^{(W_P)} \cdot I_i^{(W_P)} \le P_{rem}^{(W_P)} & (18)
\end{aligned}$$

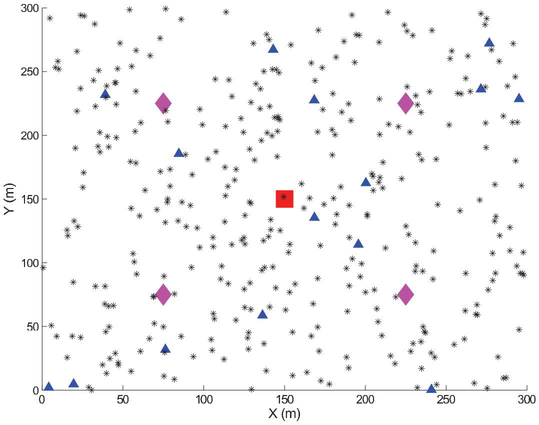


Fig. 2. Network topology of one macrocell (marked with red square), four femtocells (marked with pink diamond), 15 Wi-Fi APs (marked with blue triangle) to which 350 UEs (marked with black star) attempt to connect over a period of time for simulation.

$$\begin{aligned}
& \sum_{T\in N_{3i}} I_i^{(T)} = J_i \le 1 & \forall i \qquad (19)\\
& |I_i^{(M)} - \widetilde{I}_i^{(M)}| \le 1 - \lambda_i^{(M)} & \forall i \qquad (20)\\
& |I_i^{(F_1)} - \widetilde{I}_i^{(F_1)}| \le 1 - \lambda_i^{(F_1)} & \forall i \qquad (21)\\
& \cdots & \\
& |I_i^{(F_L)} - \widetilde{I}_i^{(F_L)}| \le 1 - \lambda_i^{(F_L)} & \forall i \qquad (22)\\
& |I_i^{(W_1)} - \widetilde{I}_i^{(W_1)}| \le 1 - \lambda_i^{(W_1)} & \forall i \qquad (23)\\
& \cdots & \\
& |I_i^{(W_P)} - \widetilde{I}_i^{(W_P)}| \le 1 - \lambda_i^{(W_P)} & \forall i \qquad (24)
\end{aligned}$$

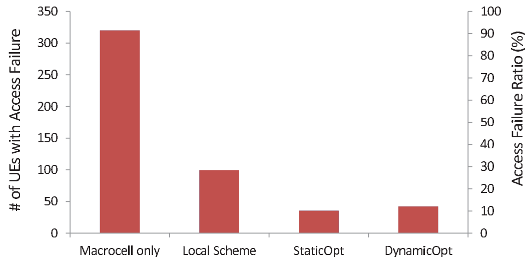
where Q_i is QoS of UE i ranging from 1 to 8, $p_{UE_i}^{(T)}$ is the amount of power allocated at cell T for UE i, and $P_{rem}^{(T)}$ is the remaining power at cell T. N_{3i} is a set of all connectable cells at UE i, and $\widetilde{I}_i^{(T)}$ is the previous indicator function result for UE i and cell T, indicating whether UE i was connected to cell T.

Constraint (14) $\sim$ (18) ensures that macrocell, femtocells, and Wi-Fi APs have enough power to allocate for connected UEs. Constraint (19) enforces that any UE should be connected to at most one cell. Lastly, constraint (20) $\sim$ (24) encourages each UE to be connected to the previous cell as far as it can: if the cell becomes unchanged, $\lambda_i^{(T)}$ is free to have any value between 0 and 1. Hence, solutions would be determined in such a way that $\lambda_i^{(T)}$ should be 1 if possible. Otherwise, $\lambda_i^{(T)}$ is enforced to be 0.

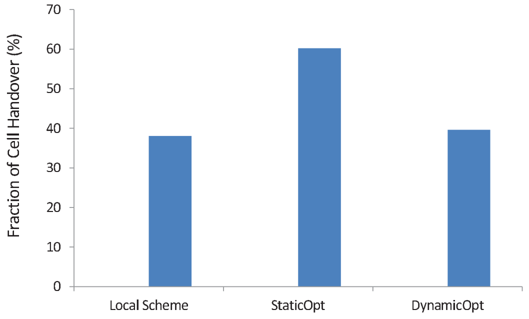
Regarding the complexity of the above binary integer programs, the solution can be calculated in a pseudo-polynomial time [11]. In our implementation, we use AMPL-CPLEX optimization engine [1] to obtain the optimal solutions.

IV. EVALUATION

We validate our dynamic inter-RAT handover mechanism in a simulated network of one macrocell, four femtocells, and 15 Wi-Fi APs deployed over 300 × 300 m^2 (Fig. 2). To simulate an overload situation, 350 UEs attempt to connect to accessible neighboring cells. We simulate the movement of the UEs with



(a) Access failure ratio



(b) Fraction of cell handover

Fig. 3. Network performance comparison of *DynamicOpt* scheme with *Local* Scheme and *StaticOpt* scheme.

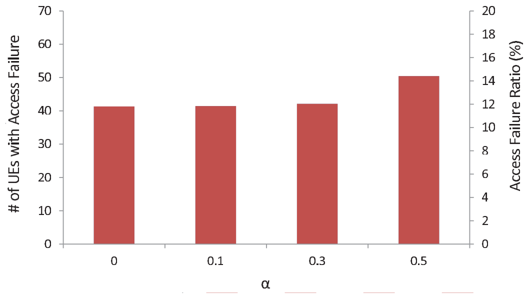
the random waypoint model [6] where the average speed is set to 20m/s, 10m/s, 5m/s, 1m/s for 30%, 10%, 20%, 40% of UEs. We generate QoS value ranging from 1 to 8 randomly for each UE. The simulation experiments run for 600 seconds.

In the experiments, we use a combined path-loss and shadowing model for radio propagation with a path-loss exponent of 3, a reference loss of 46.67 dB, and an additive white Gaussian noise $N(0, 5^2)$ in dB [5]. The transmission power of macrocell, femtocell, and Wi-Fi AP is 15, 10, and 7 dBm, respectively. The total power capacity of macrocell, femtocell, and Wi-Fi AP is 50, 6.25, and 5 W, respectively, while the unit power allocated for one UE at macrocell, femtocell, and Wi-Fi AP is 0.5, 0.125, and 0.1 W, respectively. We make all the cells initially loaded by 70% of their total power capacity.

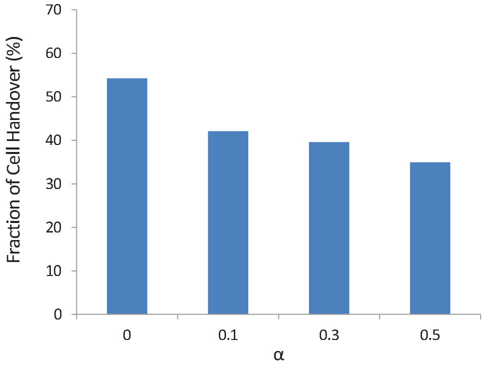
For algorithm parameters, the moving speed thresholds of v_{th1} and v_{th2} are set to 20m/s and 5m/s, respectively. The parameters of $\alpha = 0.3$, $\beta = 0.1$, and $\gamma = 1.1$ are used, unless otherwise noted.

We compare our dynamic optimization algorithm, *DynamicOpt* with two schemes: 1) *Local* scheme that selects a cell with the highest RSRP (Reference Signal Received Power) or RSSI (Received Signal Strength Indicator) in a *local* manner and 2) *StaticOpt* scheme [8] that makes a one-time static decision for the incoming cell selection. We measure access failure ratio and cell handover ratio as performance metrics. Also, we validate how our algorithm performs in terms of QoS and moving speed of UEs. Simulation results are averaged over 10 continuous cell selection cases where a cell selection process repeats every 60 seconds.

First, we compare network performance of our proposed *DynamicOpt* with other schemes in terms of access failure and handover ratios as shown in Fig. 3. In the overload situation where 91% of all the UEs experience access failure in one macrocell network, the small cell deployment of 4 femtocells and 15 Wi-Fi APs significantly mitigates access failure down to 28% with the traditional RSRP (or RSSI)-based *local* scheme as in Fig. 3(a). Both *StaticOpt* and *DynamicOpt* schemes keep the access failure ratio low around 10% even under heavy traffic environments. More importantly, our *DynamicOpt* scheme lowers the cell transition ratio by 20% compared to *StaticOpt* since *StaticOpt* is just optimized for one-time static decisions (Fig. 3(b)). It should be noted that *Local* scheme finds a locally best accessible cell, leading to low cell transition, comparable to *DynamicOpt*.



(a) Access failure ratio



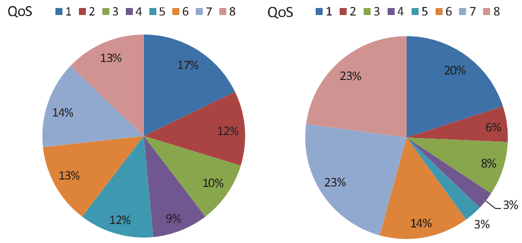
(b) Fraction of cell handover

Fig. 4. Network performance of *DynamicOpt* with respect to parameter α.

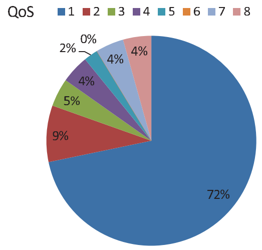
We evaluate performance dynamics as varying the factor of α in Fig. 4. As α increases, our *DynamicOpt* stresses more on the reward of maintaining the same cell that will contribute to lowering cell handovers. As α increases, the access failure ratio increases (Fig. 4(a)), whereas the cell transition rate decreases (Fig. 4(b)). Particularly, as α increases from 0 to 0.3, our *DynamicOpt* sacrifices a negligible amount of access failure less than 1%, but instead, the cell handover rate is dropped by about 15%. This implies that our algorithm provides a very efficiently optimized method to reduce handover signalling overhead.

Also, we analyze how *DynamicOpt* differentiates UEs with respect to QoS level as in Fig. 5. We look into QoS distribution of unconnected UEs for *Local*, *StaticOpt*, and *DynamicOpt* schemes. As Fig. 5(c) shows, 72% of unconnected UEs turn out to have the lowest QoS level in *DynamicOpt*. This indicates that our scheme prefers UEs with high QoS to UEs with low QoS for cell selection, aggressively dropping UEs with low QoS levels as opposed to *Local* and *StaticOpt* schemes.

Lastly, we investigate selected cell types with respect to

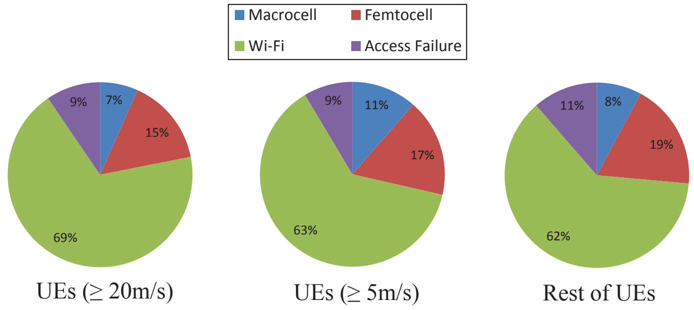


(a) Local scheme (b) *StaticOpt* scheme

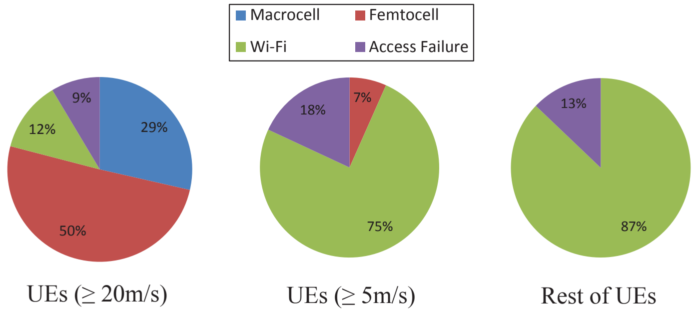


(c) *DynamicOpt* scheme

Fig. 5. QoS distribution of unconnected UEs for Local scheme, *StaticOpt*, and *DynamicOpt*.



(a) *StaticOpt* scheme



(b) *DynamicOpt* scheme

Fig. 6. Selected cell type distribution with respect to UEs' moving speed for *StaticOpt* vs. *DynamicOpt*.

moving speed of UEs for *StaticOpt* and *DynamicOpt* schemes in Fig. 6. In *StaticOpt*, the cell type distribution is irrespective of moving speed of UEs (Fig. 6(a)). On the other hand, in *DynamicOpt*, almost 80% of UEs with high mobility are connected to either a macrocell or a femtocell. As moving speed of UEs decreases, the fraction of connecting to Wi-Fi APs increases as shown in Fig. 6(b).

V. CONCLUSION

We have presented a dynamic inter-RAT handover mechanism for overloaded heterogeneous networks. By formulating crucial factors of QoS, moving speed, and cell transition into a step-wise optimization problem, we achieve low access failure, while significantly reducing cell transition ratio even under heavy traffic environments.

By inducing UEs with high mobility to be connected to macrocell and femtocells instead of Wi-Fi APs, we avoid unnecessary ping-pong effects that otherwise lead to significantly high handover signalling. Also, our algorithm prioritizes the connection establishment of UEs with high QoS to available cells. This can contribute to improving priority-based network access policy depending on user application.

In this paper, we do not explicitly consider inter-cell interference over heterogeneous networks in designing our handover mechanism. A combined method of inter-RAT handover and inter-cell interference coordination (ICIC) would be a possible next step to improve this work.

Also, we may consider some fairness among UEs in the cell overload situation for future work. Embedding a fairness metric into our formulation and analyzing a tradeoff between fairness and efficiency would be interesting research directions.

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