

A Distributed Resource Reservation Scheme for Handover Failure Reduction

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Abstract—In this letter, we propose a distributed resource reservation strategy for handover failure (HOF) reduction. The network status information that is locally available at each cell is utilized to reserve handover protection (HOP) resources in a dynamic and distributed manner. Each cell transmits downlink traffic using only the reserved HOP resources. Severe interferences to the neighboring cells on non-reserved HOP resources are therefore avoided and HO users associated to the neighboring cells transmitting in the non HOP resources can therefore reduce the HOF significantly. Numerical results following the 3GPP LTE/LTE-A network scenarios show that our proposed strategy can reduce HOF by about 40% to 70% over a conventional random allocation scheme.

Index Terms—Seamless handover, distributed resource reservation, interference management, LTE/LTE-A.

I. INTRODUCTION

WHEN a user equipment (UE) is moving out from the coverage area of the currently connected cell (*serving cell*) to another cell (*target cell*), the UE needs to detach from the serving cell and re-attach to the target cell. This procedure is called handover (HO). During HO, the serving cell sends a HO command to UE. If the UE fails to receive the HO command, HO failure (HOF) occurs, and the UE is disconnected from the network, hence needs to reconnect to the network. This results in service disruption and poor user experience, and additional signaling overhead and waste of limited network resources.

Heterogeneous network (HetNet) architecture, through underlaying small cells with macrocell, improves system's spectrum efficiency significantly [1]. However, deployment of large number of small cells in HetNet incurs more frequent HO and potentially higher HOF. Therefore, it is critical to reduce the HOF in HetNet to fully realize its capacity increase [2]. For example, the 3rd generation partnership project (3GPP) standard group emphasizes to resolve the high HOF rate in HetNet environment [2].

In most of the advanced wireless communications systems, e.g., 3GPP long-term evolution (LTE)/LTE-Advanced (LTE-A) networks, orthogonal multiple access schemes over frequency/time resource is adopted for multiple UEs in the same cell [3] so that inter-user interference can be eliminated. However, to meet high-capacity network requirement, the resources are re-used among the cells in the networks. In LTE/LTE-A, for example, single frequency network (SFN) is implemented and

the same frequency bands are shared among all the cells. This results in high inter-cell interference (ICI), especially for the HO UEs which are at the cell edge. Therefore, HOF happens due to the ICI if HO is not triggered at proper timing, which is controlled by measurement report related parameters. These parameters can be optimized to reduce HOF [4]–[6]. An almost blank subframe (ABS) has also a potential to decrease a HOF rate in LTE/LTE-A networks [2], while it requires coordination among the neighboring cells, which is unclear and challenging. To reduce the interference on the control channel, physical downlink control channel (PDCCH) orthogonalization strategy between macro and small cells has been proposed in [7] by optimizing the physical cell identity (PCI) and UE's identity at each cell. However, this orthogonalization strategy requires complex optimization and its direct extension to large HetNet system is challenging.

In this letter, we propose a distributed method that implicitly coordinates orthogonal resource allocation for HOF reduction.¹ These orthogonal resources are termed as *handover protection (HOP) resources*. Multiple HOP resources are reserved for each cell. Each cell is allowed to allocate downlink user traffic through the reserved HOP resources only. In other words, no downlink traffic is accommodated at non-reserved HOP resources. The HOP resource reservation is carried out through a *two-step reservation* in a distributed manner based on a locally unique identity (LUI), e.g., a PCI in LTE, and network status information (NSI), such as the network traffic load and congestion status. A serving cell selects one HOP resource for HO command transmission based on the LUI and NSI. Due to the uniqueness of LUI, different HOP resources are reserved for the neighboring cells. Thereby, the interferences from other cells can be mitigated.

As a specific application of HOP resource reservation, we introduce a *HOP subframe* that utilizes ABS subframes in LTE/LTE-A networks. Through computer simulation, we show that our proposed HOP resource reservation strategy significantly reduces the HOF rate by about 40% to 70% in an LTE/LTE-A HetNet network scenario.

II. HANDOVER PROCEDURE

Each UE receives a radio resource control (RRC) message from its serving cell. This message contains a list of neighboring cells and the specific event on which the UE should send a measurement report to the serving cell, e.g., Event A3 [9]. A UE measures the RSRP of those neighboring cells. HO process consists of A) event trigger, B) HO preparation, and C) HO execution.

¹The handover related parameters, such as time-to-trigger (TTT) and A3 offset, are fixed, and a target cell is selected based on reference signal received power (RSRP). However, the proposed strategy can be combined with existing approaches, such as parameter optimization methods in [4], [5], [7] and target cell selection strategies in [8].

A. Event Trigger

Event A3 is defined as a condition when the measured RSRP of a neighboring cell $P_{t,u}$ becomes higher than that of the serving cell $P_{s,u}$ by an A3 offset Δ_{A3} , i.e.,

$$P_{t,u} > P_{s,u} + \Delta_{A3}. \quad (1)$$

If (1) becomes true, Event A3 is triggered; if (1) holds for a predetermined TTT period, T_t sec, UE sends a measurement report to its serving cell, which includes the measured RSRP values and LUI of the neighboring cells [9].

B. HO Preparation

Upon receiving the measurement report from the UE, the serving cell decides whether it triggers HO. If HO is triggered, the serving cell decides a target cell [8], with which it exchanges the HO-related information via backhaul connection within T_p sec. Then, the decision and the information required for HO are signaled to the UE by an RRC message (HO command) via the downlink user data channel. If the channel quality indicator (CQI) G_s is below a threshold G_{out} , the UE fails to decode the HO command, and HOF is incurred [2].

C. HO Execution

If the UE successfully receives the HO command, it detaches from the serving cell and tries to synchronize to the target cell via random access (RA) procedure. After synchronizing to the target cell, the UE monitors the RA response (RAR) from the target cell for a predetermined time duration T_e sec. If the CQI of the target cell G_t is lower than G_{out} , UE fails to decode the RAR and HOF is declared. HO procedure is completed if RAR is successfully received within T_e sec.

D. Problem of Current Handover Procedure

As explained in Section II-B, HOF happens when $G_s < G_{out}$ and the UE fails to decode the HO command correctly from the serving cell. This is mainly because the HO UE is moving away from the serving cell, and accordingly, the signal power from the serving cell decreases while the interference from neighboring cells increases. Similarly, if $G_t < G_{out}$ when the RAR is transmitted, the UE cannot receive the RAR correctly from the target cell, as explained in Section II-C. This may be due to the reason that the HO is subject to strong interference from the just-detached serving cell. For successful HO command transmission, interference coordination is necessary. In the following section, we introduce a distributed orthogonal resource allocation approach for effective ICI reduction. As we are going to show, this proposed approach does not require explicit coordination among the neighboring cells, hence no additional signaling overhead is incurred.

III. A DISTRIBUTED HOP RESOURCE RESERVATION STRATEGY

To uniquely distinguish the neighboring cells, an LUI is assigned to each cell in most of the advanced wireless communications systems, such as 3GPP LTE/LTE-A networks. Furthermore, neighboring cells exchange their network status,

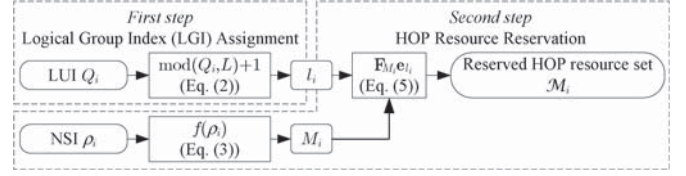


Fig. 1. Two-step reservation for HOP resources at cell i .

such as traffic load, via backhaul link to achieve load balancing [10]. The locally available information, e.g., LUI and NSI, is utilized in our proposed HOP resource reservation strategy, as explained in the following subsections.

A. Two-Step Strategy for HOP Resource Reservation

The reservation is carried out in two steps as shown in Fig. 1. Let us denote the set of HOP resources by $\mathcal{M} = \{1, \dots, M\}$. Hence there are M HOP resources. In Step 1, each cell is assigned to one logical group (LG) based on its LUI. In Step 2, multiple HOP resources are reserved to each cell based on its NSI, e.g., traffic load.

1) *Step 1—LG Index (LGI) Assignment*: Cell i is put into one of LGs according to its LUI, Q_i . The LGI of cell i , $l_i \in \mathcal{L} = \{1, \dots, L\}$, is obtained as

$$l_i = \text{mod}(Q_i, L) + 1, \quad (2)$$

where L is the number of LGs which is designed so that the neighboring cells are put into different LGs as much as possible.

2) *Step 2—HOP Resource Mapping*: Let $\mathcal{M}_i$ denote the set of the HOP resources reserved for cell i . Its size M_i is given by

$$M_i = f(\rho_i), \quad (3)$$

where $f(\rho_i)$ is a non-zero non-decreasing function over a normalized traffic load of cell i , denoted by $\rho_i \in (0, 1]$.

One of possible functions $f(\cdot)$ is a staircase function $f_{\text{stair}}(\cdot)$, given as

$$f_{\text{stair}}(\rho_i) = \lceil \rho_i / \alpha \rceil, \quad (4)$$

where $\lceil x \rceil$ is the smallest integer not smaller than x and α is a positive real-valued design parameter.

The LGI l_i is mapped onto a HOP resource vector as

$$\mathbf{s}(M_i, l_i) = \mathbf{F}_{M_i} \mathbf{e}_{l_i}, \quad (5)$$

where $\mathbf{F}_{M_i}$ is an M -by- L mapping matrix and $\mathbf{e}_l$ is an L -by-1 column vector with a 1 at the l th element, and 0's elsewhere. The number of 1's in each column of $\mathbf{F}_{M_i}$ is M_i . An example of the mapping matrix $\mathbf{F}_{M_i}$ is given as

$$\mathbf{F}_{M_i} = \sum_{m=1}^{M_i} [\mathbf{f}_m \mathbf{f}_{1+m} \cdots \mathbf{f}_{M-1+m}]^T \quad (6)$$

with $\mathbf{f}_a = \mathbf{e}_{\text{mod}(a-1, L)+1}$.

Then, the set of reserved HOP resources for cell i becomes

$$\mathcal{M}_i = \{m | m \in \mathcal{M}, s_m(M_i, l_i) = 1\}, \quad (7)$$

where $s_m(M_i, l_i) \in \{0, 1\}$ is the m th element of $\mathbf{s}(M_i, l_i)$.

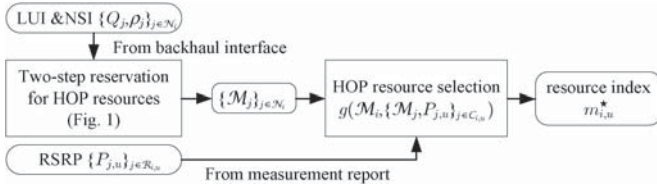


Fig. 2. Resource selection at serving cell i based on locally available information obtained from backhaul interface and a measurement report.

B. HOP Resource Selection for HO Command Transmission

Let us denote a set of neighboring cells that are included in a measurement report from UE u by $\mathcal{R}_{i,u}$ and a set of neighboring cells that exchange LUI and NSI with cell i by $\mathcal{N}_i$. The serving cell i selects one HOP resource from its reserved set $\mathcal{M}_i$ for HO command transmission based on its locally available information as shown in Fig. 2.

- 1) The serving cell i obtains the LUI and NSI $\{Q_j, \rho_j\}_{j \in \mathcal{N}_i}$ through a backhaul interface. This information enables cell i to figure out the set of reserved HOP resources $\mathcal{M}_j$ of neighboring cells $j \in \mathcal{N}_i$ with the help of (2), (4), and (5).
- 2) The serving cell i creates a neighboring cell set for UE u , $C_{i,u} = \{j \in \mathcal{R}_{i,u} \cap \mathcal{N}_i, \overline{\mathcal{M}}_j \cap \mathcal{M}_i \neq \emptyset\}$ with $\overline{\mathcal{M}}_j = \mathcal{M} \setminus \mathcal{M}_j$. Suppose $\mathcal{N}_i = \{a, b, c, d\}$, $\mathcal{R}_{i,u} = \{a, b, c\}$, and $\mathcal{M} = \{1, 2, 3, 4, 5\}$. The locally available information at cell i is $\mathcal{M}_i = \{1, 2\}$ and $\{Q_j, \rho_j\}_{j \in \mathcal{N}_i}$. Based on this information, for example, cell i figures out $\mathcal{M}_a = \{4, 5\}$, $\mathcal{M}_b = \{1\}$, and $\mathcal{M}_c = \{1, 2, 3\}$. Then, $\overline{\mathcal{M}}_c \cap \mathcal{M}_i = \emptyset$, which means that all the reserved HOP resources for cell i are also reserved for cell c . Thus, cell i cannot expect the interference avoidance from cell c . Consequently, we have $C_{i,u} = \{a, b\}$.
- 3) The serving cell i selects one HOP resource $m_{i,u}^*$ from $\mathcal{M}_i$ based on an arbitrary mapping function $g(\mathcal{M}_i, \{\mathcal{M}_j, P_{j,u}\}_{j \in C_{i,u}})$ where $P_{j,u}$ is the RSRP of cell j observed at UE u . If $C_{i,u} = \emptyset$, cell i selects one HOP resource from $\mathcal{M}_i$ randomly for UE u .

In this letter, we consider the following two selection functions.

- **Maximum Interference Avoidance (MIA):** Let us denote the index of a neighboring cell having the largest RSRP value by k , i.e., $k = \arg \max_{j \in C_{i,u}} P_{j,u}$. To avoid a high interference from this cell, a serving cell selects one of cell k 's HOP resources as follows

$$m_{i,u}^* \in \mathcal{M}_i \cap \overline{\mathcal{M}}_k. \quad (8)$$

If $|\mathcal{M}_i \cap \overline{\mathcal{M}}_k| > 1$, the serving cell i randomly selects one of them, where $|\mathcal{X}|$ denotes the cardinality of set $\mathcal{X}$.

- **Weighted Aggregate Interference Avoidance (WAIA):** With the measurement report and the traffic load information exchanged over backhaul link, the serving cell can calculate the aggregate interference on each of its reserved HOP resources. To avoid high aggregate inter-

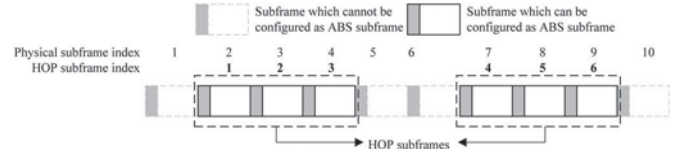


Fig. 3. Radio frame configuration with 10 subframes of LTE/LTE-A.

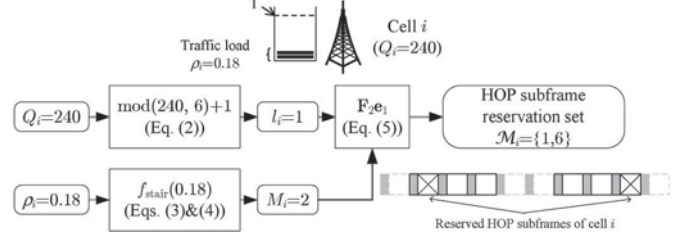


Fig. 4. Two-step reservation for HOP subframes reservation LTE/LTE-A.

ference, the serving cell selects the HOP resource with the lowest interference as

$$m_{i,u}^* = \arg \min_{m \in \mathcal{M}_i} \sum_{\substack{j \in C_{i,u}, \\ \mathcal{M}_j \cap \{m\} \neq \emptyset}} w_j s_m(\mathcal{M}_j, l_j) P_{j,u}, \quad (9)$$

where w_j is an arbitrary real-valued weight that can be calculated from the exchanged traffic load.

C. HOP Subframe Selection for RA Response at Target Cell

Once a HO UE sends the RA message to a target cell t , the target cell replies with RA response. The target cell t has no information about $\mathcal{R}_{i,u}$. Therefore, based on the knowledge of LUI and NSI of the serving cell i , $\{Q_i, \rho_i\}$, the target cell t selects one of the HOP resources that is not reserved for the serving cell i to avoid the interference from the serving cell. If the HOP resources for the target cell t are also reserved for the serving cell i , i.e., $\overline{\mathcal{M}}_i \cap \mathcal{M}_t = \emptyset$, the target cell t randomly selects one from $\mathcal{M}_t$. Thus, the selected HOP resource is given as

$$m_{t,u}^* \in \begin{cases} \overline{\mathcal{M}}_i \cap \mathcal{M}_t, & \text{if } \overline{\mathcal{M}}_i \cap \mathcal{M}_t \neq \emptyset \\ \mathcal{M}_t, & \text{otherwise.} \end{cases} \quad (10)$$

IV. APPLICATION TO 3GPP LTE/LTE-A NETWORKS

In this section, we apply the proposed HOP resource reservation strategy to LTE/LTE-A networks. In this specific application, HOP resources are the *time* domain subframes which can be configured as ABS as shown in Fig. 3, so we set $M = 6$ and $\mathcal{M} = \{1, 2, 3, 4, 5, 6\}$.

A. PCI Assignment

In LTE/LTE-A, each cell has a locally unique PCI, which is a locally assigned index, i.e., $Q_i \in \{1, \dots, 504\}$. For RSRP measurement and PDCCH demodulation, cell-specific reference signal (CRS) is multiplexed across time-and-frequency resource elements (RE). If the CRSs of the neighboring cells

TABLE I
HOF RATE REDUCTION OVER TRAFFIC LOAD ρ_i . PERCENTAGE IN BRACKET REPRESENTS THE IMPROVEMENT COMPARED TO “RANDOM SELECTION”

Traffic load ρ_i (M_i)	0 $\sim$ 0.17 (1)		0.17 $\sim$ 0.34 (2)		0.34 $\sim$ 0.51 (3)		0.51 $\sim$ 0.68 (4)		0.68 $\sim$ 0.85 (5)		0.85 $\sim$ 1 (6)	
	$S = 10$	$S = 100$	$S = 10$	$S = 100$	$S = 10$	$S = 100$	$S = 10$	$S = 100$	$S = 10$	$S = 100$	$S = 10$	$S = 100$
Random selection	2.07	4.49	4.81	8.17	7.12	18.07	10.78	25.68	13.82	33.76	16.82	37.84
HOP w/ MIA	2.07 (0%)	4.49 (0%)	2.95 (39%)	5.14 (37%)	3.44 (52%)	8.32 (48%)	4.31 (60%)	11.89 (54%)	4.85 (65%)	14.30 (58%)	16.82 (0%)	37.84 (0%)
HOP w/ WAIA	2.07 (0%)	4.49 (0%)	2.70 (44%)	4.56 (44%)	2.91 (59%)	7.99 (56%)	3.87 (64%)	10.59 (59%)	4.76 (66%)	14.12 (58%)	16.82 (0%)	37.84 (0%)

are located at the same RE position, collision happens. This collision incurs inaccurate RSRP measurement and a PDCCH demodulation error, resulting in significant degradation of system performance. To avoid the frequent CRS collisions, a frequency domain offset is introduced to the RE locations of CRS according to the PCI in LTE/LTE-A networks [3]. In total, there are six different offsets. The PCI assignment is carried out, so that the frequency domain offset at neighboring cells do not overlap as much as possible. Therefore, we can surmise that the neighboring cells are grouped into different LG with high probability by setting $L = 6$, i.e., $\mathcal{L} = \{1, 2, 3, 4, 5, 6\}$.

B. HOP Subframe Reservation

An example of the two-step HOP subframe reservation in LTE/LTE-A is shown in Fig. 4, where cell i has PCI $Q_i = 240$ and its traffic load is $\rho_i = 0.18$. From (2), LGI of cell i is $l_i = \text{mod}(240, 6) + 1 = 1$. By using the function in (4) with $\alpha = 0.17$, we have $M_i = f_{\text{stair}}(\rho_i) = 2$. With the use of $\mathbf{F}_2$ in (6), the set of reserved HOP subframes becomes $\mathcal{M}_i = \{1, 6\}$.

V. COMPUTER SIMULATION

The performance of the proposed HOP resource reservation strategy is evaluated in a realistic cellular communication environment. The simulation parameters provided in [6] are used, which follow 3GPP recommendation and the simulator has been calibrated with the result in 3GPP [2]. Multiple small cells are randomly dropped within each macro cell coverage. The transmit power value of macro cell and small cell are set to be 46 dBm and 30 dBm, respectively. A PCI is randomly assigned to each cell. Here, we set $\Delta_{A3} = 2$ dB, $T_f = 160$ msec, $T_p = 50$ msec, and $T_e = 40$ msec. UE velocity is set to be 60 km/h. The number of reserved HOP resources for each cell is calculated by (4) with $\alpha = 0.17$ and the mapping matrix given in (6) is used for HOP resource mapping. For WAIA, we set $w_j = 1$ for $j \in \mathcal{C}_{i,u}$ for simplicity.

The HOF rate reduction over traffic load ρ_i is shown in Table I. Due to the increase of interference from the dense deployment, the practical number of small cells using the same carrier frequency as the macro cell could be at most 100 within the macro cell coverage [11]. Thus, we set $S = 100$ for high-dense small cell environment, comparing $S = 10$ for low density. As a benchmark, we consider the case where M_i HOP resources are randomly selected from $\mathcal{M} = \{1, 2, 3, 4, 5, 6\}$ for each cell, i.e., there is no coordination among the cells. When traffic load is very low ($0 \leq \rho_i < 0.17$) and high ($0.85 \leq \rho_i \leq 1$), there is no performance gain for the proposed strategy. This is because there is no degree of freedom to select

the proper resources to avoid the interference. On the other hand, for medium traffic load ($0.17 \leq \rho_i < 0.85$), the proposed reservation strategy greatly reduce the HOF rate by about 40 to 70% due to the distributed interference management based on locally available network status information. Both HOP resource selection strategies, MIA and WAIA, provide similar performance improvement. This implies that avoiding the largest interference can significantly improve the HOF rate even for high-dense small cell environment.

VI. CONCLUSION

We have proposed a distributed strategy reserving resources to protect handover (HO) in neighboring cells, called HO protection (HOP) resource reservation. By doing this, significant interferences on the control channels during HO can be effectively mitigated, especially when the traffic load is low, resulting in about 40% to 70% HO failure reduction compared to the existing method. This benefit can be achieved without changing any existing network protocol and specification.

REFERENCES

- [1] A. Damnjanovic *et al.*, “A survey on 3GPP heterogeneous networks,” *IEEE Wireless Commun.*, vol. 18, no. 3, pp. 10–21, Jun. 2011.
- [2] Evolved Universal Terrestrial Radio Access (E-UTRA); mobility enhancements in heterogeneous networks (release 11), 3rd Generation Partnership Project (3GPP), Sophia Antipolis, France, TR 36.839 V11.1.0, Dec. 2012.
- [3] Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures (release 12), 3rd Generation Partnership Project (3GPP), Sophia Antipolis, France, TS 36.213 V12.2.0, Jul. 2014.
- [4] D.-W. Lee, G.-T. Gil, and D.-H. Kim, “A cost-based adaptive handover hysteresis scheme to minimize the handover failure rate in 3GPP LTE system,” *EURASIP J. Wireless Commun. Netw.*, vol. 2010, 2010, Art ID. 6.
- [5] M. Simsek, M. Bennis, and I. Guvenc, “Mobility management in HetNets: A learning-based perspective,” *EURASIP J. Wireless Commun. Netw.*, vol. 2015, 2015, Art ID. 26.
- [6] Y. Zhou, Z. Lei, and S. H. Wong, “Evaluation of mobility performance in 3GPP heterogeneous networks,” in *Proc. IEEE Veh. Technol. Conf.—Spring*, Seoul, Korea, May 2014, pp. 1–5.
- [7] S. Kucera and D. López-Pérez, “Orthogonally-filled subframes for optimum operation of co-channel LTE HetNets,” in *Proc. IEEE Int. Conf. Commun.*, Sydney, Australia, Jun. 2014, pp. 4868–4874.
- [8] D. Xenakis *et al.*, “Mobility management for femtocells in LTE-advanced: Key aspects and survey of handover decision algorithms,” *IEEE Commun. Surveys Tuts.*, vol. 16, no. 1, pp. 64–91, 1st Quart. 2014.
- [9] Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol specification (release 12), 3rd Generation Partnership Project (3GPP), Sophia Antipolis, France, TS 36.331 V12.2.0, Jul. 2014.
- [10] C. K. Ho *et al.*, “Power and load coupling in cellular networks for energy optimization,” *IEEE Trans. Wireless Commun.*, vol. 14, no. 1, pp. 509–519, Jan. 2015.
- [11] J. Kim *et al.*, “Areal capacity limit on the growth of small cell density in heterogeneous networks,” in *Proc. IEEE Global Commun. Conf.*, Austin, TX, USA, Dec. 2014, pp. 4263–4268.