Analyzing the Performance of Dual Connectivity in Control/User-plane Split Heterogeneous networks

Shankar K. Ghosh and Sasthi C. Ghosh
Advanced Computing & Microelectronics Unit
Indian Statistical Institute
Kolkata 700108, India
E-mail: shankar.it46@gmail.com and sasthi@isical.ac.in.

***Abstract*—The next generation heterogeneous networks are envisioned as multi-tier networks consisting of macro-cells, providing ubiquitous coverage and small cells, providing high data rate at hotspot areas to improve system capacity. In such heterogeneous networks, mobile terminals (MTs) experience frequent handovers causing high control overhead and link failure probability. To reduce control overhead and to ensure seamless mobility, logical separation between *control plane* and *data plane* has been evolved as a promising solution. In control/user-plane (C/U) split network architecture, macro-cell base stations provide control coverage using a low frequency band signal, whereas small cells provide high data rate transmissions to the MTs over high frequency band signals. While performing handovers over small cell base stations, throughput perceived by an MT may fall below the requested data rate. To improve the user perceived throughput at cell edges, recently *dual connectivity* (DC) has been proposed for long term evolution (LTE) cellular networks. However, analyzing the performance of DC in C/U split LTE heterogeneous networks is quite limited in the preceding literature. In this work, we analyze the performance of DC in C/U plane split network architecture explicitly considering data rate demands of the MTs, traffic arrival pattern, channel conditions as well as target call dropping probability. Our analyses reveal that the performance gain of DC over traditional hard handover is actually *conditional* on traffic load density in small cell base stations.**

I. Introduction

The next generation heterogeneous networks [1] are envisioned as a multi-tier network where macro-cell base stations provide ubiquitous coverage. Within the coverage region of macro-cells, several small cell base stations are deployed in hotspot areas to improve system capacity. While roaming across such heterogeneous networks, mobile terminals (MTs) may experience frequent handovers due to the limited coverage regions of the deployed small cell base stations. These frequent handovers cause increased control plane overhead and higher link failures. To reduce such control overhead and to ensure seamless mobility, logical separation between *control plane* and *data plane* has been evolved as a promising solution [2], [3]. In control/user-plane (C/U) split network architecture, macro-cell base stations provide control coverage using a low frequency band signal and support efficient radio resource control (RRC) procedures for the MTs. Within the footprint of the macro-cells, several small cells provide high data rate transmissions to the MTs over high frequency band signals. In C/U split network architecture, macro-cells and small cells are commonly referred to as control base stations (CBSs) and data base stations (DBSs) respectively. In addition, the concept of C/U split architecture has got enough attention in the context of long term evolution (LTE) cellular networks [4], [5]. In C/U split LTE heterogeneous networks, control plane signaling is performed to the MT by CBS through a single link, whereas user plane data is transmitted to the MTs by DBSs without consuming radio resources from the CBSs.

While performing handovers over the DBSs, throughput perceived by an MT may fall below the requested data rate due to high pathloss experienced by high frequency signals. Throughput performance degradation is quite unacceptable for applications having strict data rate requirements such as constant bit rate (CBR) video traffics. To improve the user perceived throughput at cell edges, recently *dual connectivity* (DC) has been proposed for LTE cellular networks [6], [7]. Using the DC mechanism, multiple carriers from different base stations can be aggregated to improve radio resource utilization. In principle, DC can be applied between any pair of base stations which are connected via non-ideal backhaul (X2) and operate on atleast two different frequencies. Using the support of DC mechanism, an MT can aggregate carriers from two DBSs to satisfy the data rate request at the cell edges. In [8]-[11], DC has been shown to be very effective in minimizing throughput degradation in traditional LTE cellular networks.

In C/U split architecture, DC mechanism calls for resource allocations from both current and target DBSs at the cell edge. This may cause resource scarcity under highly loaded situation leading to high call drops. The amount of resource to be allocated in turn depends on several parameters such as *data rate request*, *traffic arrival pattern*, *channel conditions* as well as *target call dropping probability*. Analyzing the performances of DC in C/U split LTE heterogeneous networks are quite limited in the preceding literature. In [12], using stochastic geometry tools, the downlink channel performance has been analyzed in terms of coverage probability and average achievable rate in DC assisted heterogeneous networks. In [13], a DC assisted handover scheme has been proposed to manage handovers between macro-cell base stations in a C/U plane split architecture for LTE cellular networks. In addition, the effect of radio link failure on handover procedures has also been analyzed while the MTs operate in DC mode. However, these analyses [12]-[13] do not consider the effect of realistic system parameters such as data rate requests and traffic arrival rate. In this work, our *objective* is to analyze the performance of DC in C/U plane split network architecture explicitly considering data rate demands of the MTs, traffic arrival pattern, channel conditions as well as target call dropping probability. Our *contributions* can be summarized as follows.

Firstly, we model the service coverage Δ as the lower bound on the expected distance upto which an MT can get the requested data rate. In contrast to the existing analyses [23], [24], where service coverage regions are modeled as *circular regions* based on only received signal strength at the MTs, in this analyses, we explicitly consider the effect of channel fading, traffic arrival rate and data rate requests of MTs to model Δ. Then, based on the expression for Δ, we derive the expression for P_{dc}, the coverage probability of an MT in DC mode. The derivation of P_{dc} explicitly considers the effect of *terminal mobility*. Finally, based on Δ and P_{dc}, we formulate the resource allocation problems for DC and traditional hard handover as Integer Linear Programs (ILPs). The objectives of the formulated ILPs are to maximize *system throughput*, where the constraint set ensures that the total demand imposed by the MTs do not exceed the total capacity. Since the total demand is highly variable because of its dependence on several dynamic factors such as call arrival rate, channel fading as well as network load, we have also analyzed the lower bound on the probability that the total demand imposed by the MTs does not exceed the system capacity. Our analyses reveal that the performance gain of DC over traditional hard handover is actually *conditional* on traffic load density in DBSs.

Rest of the paper is organized as follows. Section II presents related works. In section III, we analyze the performance of DC and traditional hard handovers in C/U split network architecture. Section IV, presents the results obtained from our proposed analytical framework. Finally, section V concludes the paper.

II. Related works

To promote the standardization of DC mechanism in heterogeneous networks, several efforts have been initiated in recent past [8]-[13]. Most of these works [8]-[11] are concerned about *heterogeneous network architectures* where an MT can receive data from both macro cell as well as small cells. In [8], the problem of traffic splitting between master evolved node B (MeNB) and secondary evolved node B (SeNB) for DC mechanism has been formulated as a multi-objective optimization problem (MOOP). This MOOP formulation explicitly considers several system parameters such as minimum data rate requirement for an MT, maximum possible data rate request of an MT and capacities of backhaul links between MeNB and SeNBs. Based on the characterization of MOOP, two different algorithms have been developed for throughput maximization and energy consumption minimization respectively. In [5], a downlink traffic scheduling (DTS) scheme for MeNB have been proposed to split the incoming traffic between SeNBs which will serve the MTs having DC support. The DTS scheme has been formulated as a mixed integer linear programming (MILP) problem, whose objective is to maximize the network throughput. This MILP formulation accounts the up-to-date system and network parameters such as capacities of the backhaul links, amount of downlink data that can be buffered in MeNB and SeNBs as well as data rates of bearers. In [9], the performance of DC has been analyzed considering realistic deployment of an Europian City. Here an opportunistic cell selection mechanism has also been proposed that aims at intra-layer load balancing. In [10], technical challenges associated with DC have been explored and potential solution directions have been investigated through system level simulation. These technical challenges include buffer status report calculation and logical channel prioritization. In [11], an efficient algorithm for user association have been proposed which is optimal for proportional fairness system upto an additive constant. This algorithm can achieve significant gains in DC mode at low network load.

Analyzing the performances of DC in *C/U split architecture* are quite limited in the preceding literature. In [12], authors have analyzed the downlink channel performance in both data and control plane for DC assisted heterogeneous networks. Here the authors have used tools from stochastic geometry to model the coverage probability and average rate achieved by MTs in heterogeneous networks. In [13], a handover scheme exploiting the benefits of DC has been proposed to improve the inter macro eNB handover performance in C/U split heterogeneous network architecture. In addition, the effect of radio link failure on handover procedures has also been analyzed. However, these analyses do not consider the effect of realistic parameters such as data rate request, traffic arrival pattern and target call dropping probability adequately. In this work, we propose an analytical framework to analyze and compare the performances of DC and traditional hard handover in a C/U split LTE heterogeneous network. Our analyses account data rate requests of the MTs, traffic arrival pattern, target call dropping probability as well as radio channel conditions.

III. Proposed analytical framework

In this section, firstly, we model the *service coverage* Δ as the lower bound on the expected distance upto which an MT can get the requested data rate. Then, using the expression for Δ, we derive the expression for P_{dc}, the coverage probability of an MT in DC mode. Finally, based on the expression for Δ and P_{dc}, we formulate the cell association problems for DC and traditional hard handover as ILPs. To carry out the analysis, we consider a C/U split network architecture where control plane and data plane are logically separated as described in [14]. Here a control base station (CBS) is providing ubiquitous coverage and support RRC procedures. Within the coverage region of the CBS, several data base stations (DBSs) are randomly deployed. The DBSs provide high data rate over small coverage regions within the footprint of the CBS. In the considered scenario, MTs are assumed to be *uniformly* distributed and moving according to random way point (RWP) mobility model [18]. Each MT is also assumed to has a *strict* *data rate* requirement for CBR video traffic. The DBSs are using orthogonal frequency division multiplexing (OFDMA) as their MAC access mechanism.

A. *Analyzing* service coverage Δ

In preceding literature [23], [24] service coverage regions have been widely modeled as *circular regions* mainly based on *Euclidean distance* and *received signal strength* (RSS) of an MT from its serving access point. This is because the throughput perceived by an MT is highly correlated with Euclidean distance and RSS values. In [23], the service coverage region of an access point has been modeled as a circular region for handover performance evaluation of voice over IP (VoIP) application. In [24], the wireless local area network (WLAN) usage efficiency have been investigated assuming circular service coverage region of WLAN access points. In practice, the area of service coverage regions are much smaller compared to that of considered in circular modeling. This is because the circular models do not consider the radio channel conditions as well as service demands of the MTs adequately. In this analysis, we explicitly consider the effect of *log normal shadow fading*, *Rayleigh fading*, *traffic arrival rate* as well as *data rate requests* of MTs to model Δ.

According to the specification of LTE systems, MT j gets r_j^{req} from DBS i if the received energy per bit compared to the spectral noise density $\left(\frac{E_b}{N_o}\right)$ through the allocated resource block (RB) is sufficient to get r_j^{req} [15]. That is:

$$\xi_{ij} \geq \xi\left(r_j^{req}\right) \tag{1}$$

where ξ_{ij} is the $\frac{E_b}{N_o}$ received by MT j from DBS i through the allocated RB and $\xi\left(r_j^{req}\right)$ is the target $\frac{E_b}{N_o}$ threshold to get r_j^{req} and can be computed as [20]:

$$\xi\left(r_j^{req}\right) = \frac{B}{r_j^{req}} \times \left(2^{\frac{r_j^{req}}{B}} - 1\right). \tag{2}$$

Here B is the bandwidth of an RB. Assuming that the intra cell interference is negligible and the cumulative effect of interference is much higher than that of thermal noise as considered in [15] and [17], ξ_{ij} can be computed as:

$$\xi_{ij} = \frac{B}{r_j^{req}} \times \frac{P_{ij}}{\sum_{k\neq i} P_{kj} \times P_{col}} \tag{3}$$

where P_{ij} is the power received by MT j from DBS i through the allocated RB and P_{col} is the sub-carrier collision probability. Since resource allocations in current and target DBSs are independent [15], [17], P_{col} can be computed as:

$$P_{col} = \frac{Mean\ allocated\ resource}{Total\ amount\ of\ resource} = \frac{M \times u}{U} \tag{4}$$

where M is the average number of active MTs within the coverage region of a DBS, u is the call arrival rate and U is the total number of RBs in a DBS. Here, we are assuming that each call is served by a single RB of the serving DBS. Therefore, $M \times u$ represents the mean demand for RBs on a DBS. It may be noted that the value of u depends on the type of traffic. Here CBR traffic arrival is assumed to follow *Poisson* distribution with rate λ $(6 \sim 16)$ similar to that of [16]. Accordingly, u is equal to λ for CBR traffic.

To provide the just required $\frac{E_b}{N_o}$ to satisfy r_j^{req}, ξ_{ij} should be atleast $\xi\left(r_j^{req}\right)$. Assuming $\xi_{ij} = \xi\left(r_j^{req}\right)$, and using equation (4), from equation (3) we get:

$$\begin{aligned} \xi\left(r_j^{req}\right) &= \frac{B}{r_j^{req}} \times \frac{P_{ij} \times U}{\sum_{k\neq i} P_{kj} \times P_{col} \times M \times u} \\ \Rightarrow \frac{\sum_{k\neq i} P_{kj}}{P_{ij}} &= \frac{B \times U}{M \times u \times r_j^{req} \times \xi\left(r_j^{req}\right)}. \end{aligned} \tag{5}$$

To compute P_{ij}, the power received by MT j from DBS i through the allocated RB, we first compute the power attenuation at the receiver end considering path loss, log normal shadowing and fast Rayleigh fading as follows [21]:

$$PL_{ij} = C \times d_{ij}^{-n} \times 10^{\frac{\phi}{10}} \times \pi_{ij} \tag{6}$$

where PL_{ij} is the attenuation of the power transmitted from DBS i and computed at MT j; C is the constant which depends on the parameters of the considered path loss model such as frequency of transmission, height of the base station antenna and height of the mobile station antenna; d_{ij} is the distance between DBS i and MT j; n is the path loss exponent depending on the considered path loss model; ϕ is the Gaussian distributed random variable with zero mean and standard deviation σ such that $10^{\frac{\phi}{10}}$ is log normally distributed; π_{ij} represents short term instantaneous power attenuation between MT j and DBS i due to Rayleigh fading, i.e., magnitude of the received signal envelop at MT j has a Rayleigh distribution. The probability density function (*pdf*) of π_{ij} is:

$$f_\pi(x) = \frac{x}{2\eta^2} \times e^{-\frac{x}{2\eta^2}}, \quad \eta \geq 0 \tag{7}$$

where η^2 is the variance of received power. In the subsequent analysis, we assume that all DBSs have *equal* downlink transmission power as the performance gain of DC over traditional hard handover is maximized when the MT is served with equal data rates by the serving DBSs [7]. Such an assumption is common in many studies such as [19]. Since, the allocated power to all the MTs are equal, power received at the receiver end is *proportional* to the signal path power attenuation. Accordingly, from Equations (5) and (6) we get:

$$\begin{aligned} \frac{\sum_{k\neq i} d_{kj}^{-n} 10^{\frac{\phi_{kj}}{10}} \pi_{kj}}{d_{ij}^{-n} 10^{\frac{\phi_{ij}}{10}} \pi_{ij}} &= \frac{B \times U}{M \times u \times r_j^{req} \times \xi\left(r_j^{req}\right)} \\ \Rightarrow d_{ij}^n &= \frac{K}{Y_{ij}} \times X_{ij} \end{aligned} \tag{8}$$

ISBN 978-3-903176-13-3 © IFIP

where $Y_{ij} = \sum_{k \neq i} d_{kj}^{-n} X_{kj}$, $X_{ij} = 10^{\frac{\phi_{ij}}{10}} \pi_{ij}$ and $K = \frac{B \times U}{M \times u \times r_j^{req} \times \xi\left(r_j^{req}\right)}$ is a constant. We know that $d_{kj}^{-n} X_{kj},\ k \neq i$ are independent and log-normally distributed random variables with logarithmic mean $\mu + 40\log(d_{kj})$ dB and standard deviation ρ dB [21]. It is also well known that, the distribution of a sum of independent and log normally distributed random variables has no closed form expression [22]. As a result, closed form expression for the *pdf* of d_{ij} is also not known. To obtain a lower bound on $\mathbb{E}[d_{ij}]$, we first compute the expectation of $\log(d_{ij})$ and then apply *Jenson's inequality*. Taking logarithm in both sides of Equation (8) and applying *linearity* of expectation we get:

$$\mathbb{E}[\log(d_{ij})] = \frac{\log(K)}{n} + \frac{1}{n}\left(\mathbb{E}\left[\log(X_{ij})\right] - \mathbb{E}\left[\log(Y_{ij})\right]\right) \quad (9)$$

It may be noted that X_{ij} is the product of two random variables representing log normal shadowing and Rayleigh fading. Assuming that the log normal shadowing and Raylegh fading components are independent, the *pdf* of X_{ij} can be approximated as [21]:

$$f_X(x) = \frac{10}{\ln 10\sqrt{2\pi}\rho x} exp\left[-\frac{(10\log(x) - \mu)^2}{2\rho^2}\right] \quad (10)$$

where μ and ρ are the mean and standard deviation of $\log\left(X_{ij}\right)$ respectively and can be computed as $\mu = 10\log\left(2\eta^2\right) - 2.5$ dB and $\rho = \sqrt{\sigma^2 + 5.57^2}$ dB. Since X_{ij} is a non-negative random variable, $\mathbb{E}\left[\log(X_{ij})\right]$ is computed as $\int_0^\infty \log(x) f_X(x)dx$. Since exponential functions of the form e^{p^2} are not *integrable* for real values of p, we have computed the value of $\mathbb{E}\left[\log(X_{ij})\right]$ using Simpson's rule for solving numerical integration. Here, error bound has been set to 0.0001.

Note that Y_{ij} is a summation of a series of independent log normally distributed random variables. We know that it has no closed form expression. However, the resultant distribution can be well approximated by another lognormal random variable [22]. To estimate the parameters of the resultant log-normal distribution, we have employed the *Fenton-Wilkinson* method. This method has been shown to have better accuracy regarding parameter estimation of the resultant log normal distribution [21], [22]. Following the Fenton-Wilkinson method, the *pdf* of Y_{ij} can be approximated as:

$$f_Y(x) = \frac{10}{\ln 10\sqrt{2\pi} b_{ij} x} exp\left[-\frac{(10\log(x) - v_{ij})^2}{2b_{ij}^2}\right] \quad (11)$$

where v_{ij} is computed as:

$$v_{ij} = 10\log\left[1.1247\eta^2\sqrt{10^{\frac{\rho^2}{10}}}\sum_{k\neq i} d_{kj}^n\right] - \frac{b_{ij}^2}{2}, \text{ where}$$

$$b_{ij}^2 = 10\log\left\{1 + \frac{\left(10^{\frac{\rho^2}{10}} - 1\right)\sum_{k\neq i} d_{kj}^{-n}}{\left(\sum_{k\neq i} d_{kj}^{-n}\right)^2}\right\}.$$

Similar to X_{ij}, Y_{ij} is a non-negative random variable. Hence, the value of $E[\log(Y_{ij})]$ has been computed as $\int_0^\infty \log(x) f_Y(x)dx$. Here also we employ Simpson's rule where error bound has been set to 0.0001. Substituting the value of $E[\log(X_{ij})]$ and $E[\log(Y_{ij})]$ in Equation (9), the final expression for $\mathbb{E}[\log(d_{ij})]$ can be written as:

$$\begin{aligned} \mathbb{E}[\log(d_{ij})] &= \frac{\log(K)}{n} + \frac{1}{n}\int_0^\infty \log(x) f_X(x)dx \\ &- \frac{1}{n}\int_0^\infty \log(x) f_Y(x)dx \end{aligned} \quad (12)$$

To compute the lower bound Δ on $\mathbb{E}\left[d_{ij}\right]$ from $\mathbb{E}\left[\log\left(d_{ij}\right)\right]$, we apply *Jensen's inequality*. The Jensen's inequality states that if R is a random variable and τ is a convex function, then $\tau(\mathbb{E}[R]) \leq \mathbb{E}\left(\tau(R)\right)$. Since 10^x is a convex function for real values of x, applying Jensen's inequality we get:

$$\Delta = 10^{E[\log(d_{ij})]} = \frac{K^{\frac{1}{n}} \times 10^{\frac{1}{n}\int_0^\infty \log(x) f_X(x)dx}}{10^{\frac{1}{n}\int_0^\infty \log(x) f_Y(x)dx}} \quad (13)$$

In the next subsection, based on Δ, we derive the expression for P_{dc}, the coverage probability of an MT in DC mode.

B. *Analyzing* coverage probability in DC mode

In this section, we derive the expression for P_{dc}, the coverage probability of an MT in DC mode. The derivation of P_{dc} explicitly considers the effect of *terminal mobility*. It may be noted that DC mode enables an MT to simultaneously receive data from two DBSs operating on different carrier frequencies [7]. Here, the cumulative data rate obtained by an MT is the summation of the data rates obtained from different DBSs over different carrier frequencies. The performance gain of DC over traditional hard handover be maximized when the MT is served with equal data rates by the serving DBSs [7].

We model the service coverage region of current and target DBSs by two circles each having *unit* radius by normalizing the value of Δ. It may be noted that in contrast to the existing analyses [23], [24] where *circular* models are based on *Euclidean distance* and RSS values, in this work, we have considered the effect of *log normal shadow fading*, *Rayleigh fading*, *traffic arrival rate* as well as *data rate requests* of MTs to model Δ. We consider that the current DBS is centered at

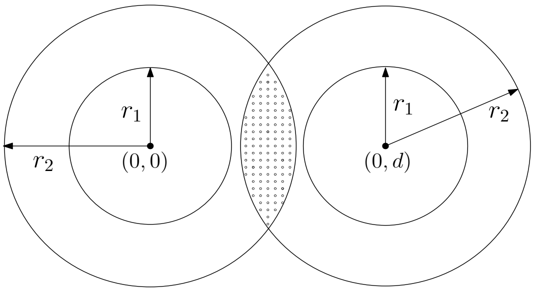

Fig. 1: Considered system model

location $(0,0)$ and the target DBS is centered at $(0,d)$, where $d < 1$ (depicted in Figure 1). We denote by ψ_1 and ψ_2 the random variables representing normalized distance of an MT from current and target DBSs respectively. Further, r_1 and r_2 denotes the normalized value of Δ and δ respectively, where δ is the lower bound of the expected distance upto which an MT gets *half* of the requested data rate. Clearly, δ can be obtained from Equation (13). In this analysis, we consider that, an MT is served in DC mode when the MT is getting the requested data rate neither from current DBS nor from target DBS, but the cumulative data rate from both the base stations satisfy the requested data rate. More formally, an MT is served in DC mode when both the events E_1 $(r_1 \le \psi_1 \le r_2)$ and E_2 $(r_1 \le \psi_2 \le r_2)$ occur simultaneously (depicted by dotted region in Figure 1). Now, for an MT traveling under RWP mobility model within a circle of unit radius, the *pdf* of the distance of the MT from center of a circle can be approximated using polynomial approximation method as [23],[25]:

$$f_\psi(x) = \frac{6x}{257}(1-x^2)(189-44x^2-18x^4)$$

Since ψ_1 and ψ_2 are two independent and identically distributed random variables with *pdf* $f_\psi(x)$, the expression for P_{dc} can be computed as:

$$\begin{aligned} P_{dc} &= P\{E_1 \cap E_2\} = P\{E_1\} \times P\{E_2\} \\ &= \left[\int_{r_1}^{r_2} f_\psi(x)dx\right]^2 \\ &= 4.84t^4 - 5.94t^6 + 1.38t^8 + 0.48t^{10} \\ &\quad -0.11t^{12} - 0.01t^{14} + 0.0025t^{16} \end{aligned} \tag{14}$$

where $t^i = r_2^i - r_1^i$, $i \in \{4,6,8,10,12,14,16\}$.

C. *Performance analyses of* DC *and hard handover*

In this subsection, we formulate the throughput optimization problem for traditional hard handover and DC as ILPs based on the expression of P_{dc}. The *objective* of the formulated ILPs are to maximize system throughput subject to the *resource constraint* that the total demand T for RBs does not exceed the *total capacity*. Here the total capacity denotes the total number of RBs available in current and target DBS, i.e., $2U$. It may be noted that T is a highly variable quantity because it depends on several dynamic factors such as call arrival rate, channel fading as well as network load. So, it is worthy to analyze a *lower bound* α on the probability that the total demand imposed by the MTs does not exceed the system capacity, i.e., $\mathbb{P}(T < 2U) \ge \alpha$.

Performance model for DC: To formulate the ILPs, we first determine A, the set of MTs that can be served in DC mode and B, the set of MTs that can be served in traditional hard handover mode without using DC facility. It may be noted that these ILP formulations are based on r_1 and r_2. Since, the MTs are uniformly distributed, the cardinality of A can be computed as $|A| = MP_{dc}$. Similarly, the cardinality of B is computed as $|B| = M(1-P_{dc})$. Corresponding to A and B, we introduce two sets of binary variables as follows.

$$x_i^A = \begin{cases} 1 & \text{if MT } i \text{ of } A \text{ is selected for association.} \\ 0 & \text{otherwise.} \end{cases}$$

$$x_j^B = \begin{cases} 1 & \text{if MT } j \text{ of } B \text{ is selected for association.} \\ 0 & \text{otherwise.} \end{cases}$$

Here, $i \in \{1,2,\dots|A|\}$ and $j \in \{1,2,\dots|B|\}$. The objective function S is the system throughput which can be computed as:

$$S = \sum_{i=1}^{|A|} x_i^A \times r_i^{req} + \sum_{j=1}^{|B|} x_j^B \times r_j^{req} \tag{15}$$

To serve a call of an MT belonging to set A, each of the current and target DBSs need to allocate one RB to the co-ordinating MT, i.e., 2 RBs are needed to serve a call. In contrast to set A, to serve a call of an MT belonging to set B, only one RB need to be allocated either by current DBS or by target DBS. Assuming CBR traffic arrival, the total demand T for RBs can be computed as $\lambda \sum_{i=1}^{|A|} 2x_i^A + \lambda \sum_{j=1}^{|B|} x_j^B$, where λ denotes the call arrival rate for CBR traffic. Since the total number of RBs in current and target DBSs are constant, the total demand for RBs should be less than the total capacity to avoid call drop. Hence, the following constraint must hold:

$$T \le 2U \Rightarrow \lambda \sum_{i=1}^{|A|} 2x_i^A + \lambda \sum_{j=1}^{|B|} x_j^B \le 2U \tag{16}$$

So, the overall ILP formulation for throughput optimization using DC mechanism is as follows.

$$\begin{aligned} \text{Maximize} \quad & S = \sum_{i=1}^{|A|} x_i^A \times r_i^{req} + \sum_{j=1}^{|B|} x_j^B \times r_j^{req} \\ \text{subject to} \quad & \lambda \sum_{i=1}^{|A|} 2x_i^A + \lambda \sum_{j=1}^{|B|} x_j^B \le 2U \\ & x_i^A \in \{0,1\},\ x_j^B \in \{0,1\} \end{aligned}$$

Performance model for hard handover: In hard handover mode, an MT is connected to only one DBS at any time and therefore can not be served in DC mode, i.e., $|A| = 0$ and $|B| = M$. Accordingly, $P_{dc} = 0$. Putting these values in Equations (15) and (16), an ILP formulation for hard handover mechanism can be obtained similar to that of DC as follows.

$$\begin{aligned} \text{Maximize} \quad & \sum_{j=1}^{M} x_j^B \times r_j^{req} \\ \text{subject to} \quad & \lambda \sum_{j=1}^{M} x_j^B \leq 2U \\ & x_j^B \in \{0, 1\} \end{aligned}$$

D. Analyzing lower bound on α

To ensure a lower bound α on the probability that a call is served successfully, the following probabilistic constraint has to be satisfied:

$$\mathbb{P}(T < 2U) \geq \alpha \Rightarrow \mathbb{P}(T \geq 2U) \leq 1 - \alpha \tag{17}$$

Using Markov's inequality we get:

$$\mathbb{P}(T \geq 2U) \leq \frac{\mathbb{E}[T]}{2U} \tag{18}$$

Assuming x_i^As and x_j^Bs are equally likely of being selected, $\mathbb{E}[T]$ can be computed using *linearity of expectation* as follows.

$$\begin{aligned} \mathbb{E}[T] &= \lambda \sum_{i=1}^{|A|} 2\mathbb{E}\left[x_i^A\right] + \lambda \sum_{j=1}^{|B|} \mathbb{E}\left[x_j^B\right] \\ &= \frac{2\lambda|A|}{M} + \frac{\lambda|B|}{M} = \lambda\left(1 + P_{dc}\right) \end{aligned} \tag{19}$$

From Equations (17) and (18), we get:

$$\alpha \geq 1 - \frac{\mathbb{E}[T]}{2U} \tag{20}$$

Putting the value of $\mathbb{E}[T]$ in Equation (20) we get:

$$\alpha \geq 1 - \frac{\lambda\left(1 + P_{dc}\right)}{2U} \tag{21}$$

It may be noted that for a given λ, U and P_{dc}, Equation (21) depicts a lower bound on α. A similar lower bound can be found for hard handover mechanism putting $P_{dc} = 0$.

IV. Numerical results and discussions

In this section, we discuss the results obtained from our proposed analytical framework. First, we show the effect of number of MTs and call arrival rate on Δ and P_{dc} respectively, and then show how system throughput varies with number of MTs and call arrival rate. The considered parameter values are depicted in Table I. Bandwidth of each DBS has been set to 10 MHz. Here MTs are assumed to have a data rate requirements for different CBR *youtube* video standards. The considered data rates for *youtube* video standards are 1.5 Mbps (YouFlash), 0.2 Mbps (YouHtml), 2.5 Mbps (YouHD) and 2.7 Mbps (YouMob) [26].

TABLE I: Parameter settings

Parameter	Value	Parameter	Value
η^2 [21]	1	σ [21]	8
α [16]	0.1	λ [16]	$6 \sim 16$
U	50	n [21]	4

Figure 2 depicts the effect of number of MTs in the system on service coverage (shown in log scale). Here the number of MTs vary from 1000 MTs to 5500 MTs with a step of 500 MTs. Call arrival rate of CBR traffic has been set to 8. The result shows that Δ shows a decreasing trend with increasing traffic load. The value Δ also decreases with increasing data rate requests. The reasons behind are as follows. Since subcarrier allocation in adjacent DBSs are independent, and the subcarrier collision probability increases with increasing traffic load, the cell edge users suffer from higher inter-cell interference as the network traffic load increases. As a result, for a fixed call arrival rate, Δ shows a decreasing trend with increasing traffic load. On the other hand, for a fixed network traffic load, increasing data rate request demands for higher $\frac{E_b}{N_o}$ as well. Since power transmitted through each subcarrier is constant, achievable $\frac{E_b}{N_o}$ by an MT is limited by pathloss, log-normal shadow fading and Raleigh fading effects. As a result, Δ decreases as the data rate request increases.

Figure 3 depicts the effect of call arrival rate on P_{dc}. Here call arrival rate varies from 6 to 16 with a step of 1 unit. The number of MTs in the system has been set to 1000 MTs. The result shows that P_{dc} shows a decreasing trend with increasing call arrival rate. It may also be noted that the P_{dc} value decreases with increasing data rate request. The reasons behind are as follows. An MT is served in DC mode if it can not be served by either current DBS or target DBS. An increased call arrival rate demands for higher number of RBs. On the other hand, total number of RBs in current and target DBSs are constant. As a result, the probability of an MT being served in DC mode decreases with increasing call arrival rate.

Figure 4 depicts the effect of traffic load on P_{dc}. Here the number of MT varies from 1000 to 10000 MTs with a step of 1000 MTs. The call arrival rate for CBR traffic has been set to 8. The result shows that P_{dc} shows a decreasing trend with increasing traffic load. It may also be observed that for a fixed traffic load, P_{dc} value shows a decreasing trend with increasing data rate request. The reasons behind are as follows. The probability of an MT being served in DC mode depends on the area of overlapping coverage region between current and target DBSs. With increasing traffic load, the service coverage region shows a decreasing trend (depicted in Figure 2). As a result, P_{dc} value also decreases with increasing traffic load. On the other hand, higher data rate request demands for higher $\frac{E_b}{N_o}$ values which in turn calls for higher demand for RBs. Since, total number of RBs in current and target DBSs are constant, the value of P_{dc} decreases with increasing data rate request.

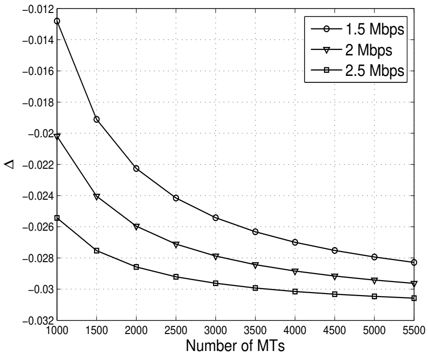

Fig. 2: Δ vs. number of `MTs`

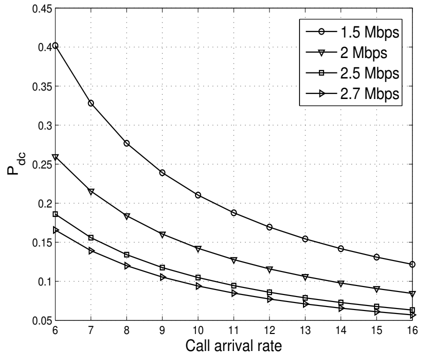

Fig. 3: P_{dc} vs. call arrival rate

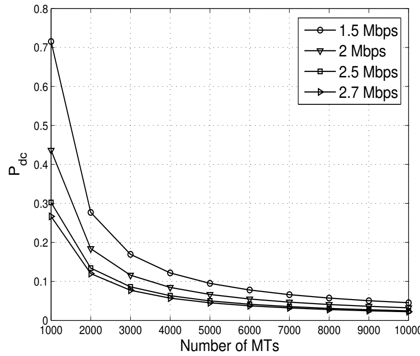

Fig. 4: P_{dc} vs. number of `MTs`

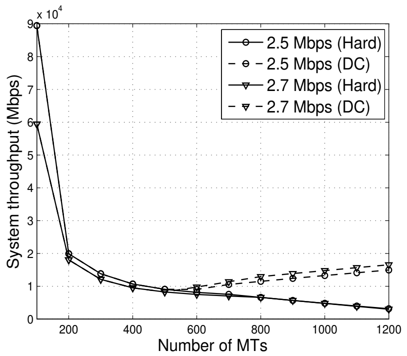

Fig. 5: System throughput vs. number of `MTs`

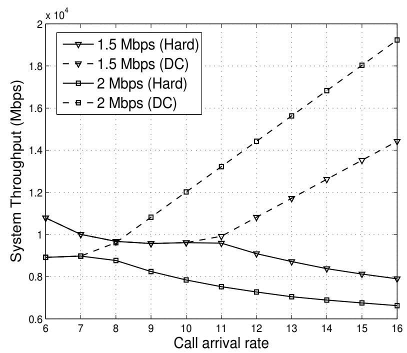

Fig. 6: System throughput vs. call arrival rate

Comparison between `DC` and hard handover

In this subsection, we compare `DC` with hard handover based on our proposed analytical model. Here we consider *system throughput* as the performance evaluation metric. We have used `GNU` linear programming kit (`GLPK`) [27] to obtain system throughput values from Equation (15). Figure 5 depicts the effect of number of `MTs` on system throughput. Here number of `MTs` vary from 100 `MTs` to 1200 `MTs` with a step of 100 `MTs`. The call arrival rate of `CBR` traffic has been set to 7. The result shows that for both 2.5 `Mbps` and 2.7 `Mbps` data rate request, no performance gain of `DC` over hard is achieved when network traffic load is less than 500 `MTs`. As the traffic load increases beyond 500 `MTs`, the performance gain of `DC` over hard handover shows an increasing trend (performance gain upto 66 percent). The reason behind this is as follows. When the number of `MTs` present in the system is low, expected number of `RBs` to satisfy the data rate requests of all the `MTs` are low. As a result, all of the requests can be served in hard mode. As the traffic load grows beyond 500 `MTs`, the requested number of `MTs` to serve the calls also increases. Consequently, the cell edge users need to be served in `DC` mode as their demands for `RBs` can be served by neither current `eNB` nor target `eNB`. Consequently, the performance gain of `DC` over hard shows an increasing trend for both the considered data rates.

Figure 6 depicts the effect of call arrival rate on system throughput. Here call arrival rate varies from 6 unit to 16 unit with a step of 1 unit. The number of `MTs` has been set to 800 `MTs`. The result shows that the performance gain of `DC` over hard is zero when call arrival rate is less than a particular threshold. For 2 `Mpbs` and 1.5 `Mpbs` data rates, the threshold values are 7 and 10 respectively. As the call arrival rate increases beyond the threshold, the performance gain of `DC` over hard shows an increasing trend. The result shows that the performance gain of `DC` over hard is upto 45 percent for 1.5 `Mbps` data rate and upto 63 percent for 2 `Mbps` data rate. The reason behind are as follows. The demand for `RBs` to serve the requested data rate increases with increasing call arrival rate. The demand for `RBs` can be served in hard mode when the call arrival rate is low. As the call arrival rate increases, the cell edge users need to be served in `DC` mode. As a result, performance gain in `DC` mode also increases.

From Figures 5 and 6, we conclude that `DC` is effective when demand for `RBs` is very high, i.e., when call arrival rate is very high or large number of `MTs` are present in the system.

V. Conclusion

In this work, we have analyzed and compared the system throughput obtained under `DC` and traditional hard handover mode in `C/U` plane split `LTE` heterogeneous network architecture. Our analysis explicitly considers the data rate demands of the MTs, traffic arrival pattern, channel conditions as well as target call dropping probability. Based on the results obtained from our proposed analytical framework, we conclude that the performance gain of DC over traditional hard handover is actually *conditional* on traffic load density in DBSs. More specifically, DC is effective when demand for RBs is very high.

VI. Future research plan

Our future research plan includes the following:

- Incorporating *call dropping probability* as a performance evaluation metric in the proposed analytical framework.
- Analyzing the performances of *semisoft handover* and *coordinated multipoint (CoMP)* along with hard handover and DC.
- Detailed system level simulation to validate the analytical framework.

References

[1] X. Wang, M. Xiao, J. Yi, C. Feng and F. Jiang, "On the performance analysis of downlink heterogeneous networks with dual connectivity", *In the proc. of 8th International Conference on Wireless Communications & Signal Processing (WCSP)*, 2016.

[2] A. Mohamed, O. Onireti, M. A. Imran, A. Imran and R. Tafazolli, "Control-Data separation architecture for cellular radio access networks: A survey and outlook", *IEEE Communications Surveys & Tutorials*, vol. 18, no. 1, pp. 446-465, 2016.

[3] L. Du, N. Zheng, H. Zhou, Y. Liu, Z. Zhao, J. Chen, T. Yu, X. Qian, J. Chi, X. Liu, Z. Chen and G. Liu, "C/U split multi-connectivity in the next generation new radio system", *In the proc. of IEEE 85th Vehicular Technology Conference (VTC Spring)*, pp. 1-5, 2017.

[4] H. Ishii, Y. Kishiyama and H. Takahashi, "A novel architecture for LTE-B: C-plane/U-plane split and phantom cell concept", *In the proc. of IEEE Globecom Workshops*, pp. 624-630, 2012.

[5] M. Pan, T. Lin, C. Chiu and C. Wang, "Downlink traffic scheduling for LTE-A small cell networks with dual connectivity enhancement", *IEEE Communications Letters*, vol. 20, no. 4, pp. 796-799, 2016.

[6] C. Rosa, K. Pedersen, H. Wang, P. Michaelsen, S. Barbera, E. Malkamki, T. Henttonen and B. Sbire, "Dual Connectivity for LTE Small Cell Evolution: Functionality and Performance Aspects", *IEEE Communications Magazine*, vol. 54, no. 6, pp. 137-143, 2016.

[7] H. Wang, C. Rosa and K. I. Pedersen, "Dual connectivity for LTE-advanced heterogeneous networks", *Wireless networks*, vol 22, no. 4, pp. 1315-1328, 2016.

[8] S. Boumard, I. Harjula, K. Horneman and H. Hu, "Throughput and energy consumption trade-off in traffic splitting in heterogeneous networks with dual connectivity", *In the proc. of IEEE 28th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, 2017.

[9] G. Pocovi, S. Barcos, H. Wang, K. I. Pedersen and C. Rosa, "Analysis of heterogeneous networks with dual connectivity in a realistic urban deployment", *In the proc. of IEEE 81st Vehicular Technology Conference (VTC Spring)*, pp. 1-5, 2015.

[10] S. C. Jha, K. Sivanesan, R. Vannithamby and A. T. Koc, "Dual connectivity in LTE small cell networks", *In the proc. of IEEE Globecom Workshops*, pp. 1205-1210, 2014.

[11] N. Prasad and S. Rangarajan, "Exploiting dual connectivity in heterogeneous cellular networks", *In the proc. of 15th International Symposium on Modeling and Optimization in Mobile, Adhoc and wireless networks (WiOpt)*, pp. 1-8, 2017.

[12] X. Wang, M. Xiao, J. Yi, C. Feng and F. Jiang, "On the performance analysis of downlink heterogeneous networks with dual connectivity", *In the proc. of 8th International Conference on Wireless Communications & Signal Processing (WCSP)*, pp. 1 - 6, 2016.

[13] P. J. Hsieh, W. S. Lin, K. H. Lin and H. Y. Wei, "Dual-Connectivity prevenient handover scheme in control/user-plane split networks", *IEEE Transactions on Vehicular Technology*, vol. 67, no. 4, pp. 3545-3560, 2018.

[14] A. Mohamed, O. Onireti, M. A. Imran, A. Imran and R. Tafazolli,"Control-Data Separation Architecture for Cellular Radio Access Networks: A Survey and Outlook", *IEEE Communication Surveys & Tutorials*, vol. 18, no. 1, pp. 446-465, 2016.

[15] H. Lee, H. Son and S. Lee, "Semisoft Handover Gain Analysis Over OFDM-Based Broadband Systems", *IEEE Transactions on Vehicular Technology*, vol. 58, no. 3, pp. 1443-1453, 2009.

[16] B. Chang and J. Chen, "Cross-layer-based adaptive vertical handoff with predictive RSS in heterogeneous wireless networks", *IEEE Transactions on Vehicular Technology*, vol. 57, no. 6, pp. 3679-3692, 2008.

[17] S. Agarwal, S. De, S. Kumar and H. M. Gupta, "QoS-aware downlink cooperation for cell-edge and handoff users", *IEEE Transactions on vehicular technology*, vol. 64, no. 6, pp. 2512-2527, 2015.

[18] L. Irio, R. Oliveira and L. Bernardo, "Aggregate interference in random waypoint mobile networks", *IEEE Communication letters*, vol. 19, no. 6, pp. 1021-1024, 2015.

[19] J. Zang, R. Chen, J. G. Andrews, A. Ghosh and R.W. Heath, "Networked MIMO with clustered MIMO precoding", *IEEE Transactions on Wireless Communication*, vol. 8, no. 4, pp. 1910-1921, 2009.

[20] S. K. Ghosh and S. C. Ghosh, "A goodness based vertical handoff algorithm for heterogeneous networks", *In proc. of the wired/wireless internet communications (WWIC)*, vol. 9674, pp. 254-267, 2016.

[21] H. Fu and D. I. Kim, "Analysis of throughput and fairness with downlink scheduling in WCDMA networks", *IEEE Transactions on Wireless Communications*, vol. 5, no. 8, pp. 2164-2174, 2006.

[22] N. C. Beaulieu, A. A. Abu-Dayya and P. J. McLane, "Estimating the distribution of a sum of independent lognormal random variables", *IEEE Transactions on Communications*, vol. 43, pp. 2869-2873, 1995.

[23] T. M. Ali and M. Saquib, "Analytical framework for WLAN-cellular voice handover evaluation", *IEEE Transactions on Mobile Computing*, vol. 12, no. 3, pp. 447-460, 2013.

[24] N. K. Panigrahy and S. C. Ghosh, "Analyzing the effect of soft handover on WLAN usage efficiency under load condition", *In the proc. of IEEE 14th International Symposium on Network Computing and Applications (IEEE NCA)*, 2015.

[25] E. Hyytia, P. Lassila and J. Virtamo, "Spatial node distribution of the random waypoint mobility model with applications" *IEEE Transactions on Mobile Computing*, vol. 5, no. 6, pp. 680-694, 2006.

[26] A. Rao, A. Legout, Y. Lim, D. Towsley, C. Barakat and W. Dabbous, "Network characteristics of video streaming traffic", *In proc. of the seventh Conference on Emerging Networking Experiments and Technologies (CoNEXT)*, 2011.

[27] https://www.gnu.org/software/glpk/