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Research Article

Distributed Load Balancing for Multi-User Multi-Class Traffic in MIMO-LTE-A Networks

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Abstract: In LTE network, load imbalance is the crucial issue which needs to be handled in order to exploit most of the benefit from LTE without degrading the throughput. In this study, we have proposed a Distributed Load Balancing for Multi-user Multi-class Traffic in MIMO-LTE Networks. First, we have proposed a robust load balancing framework to efficiently handle the traffic and also to keep the throughput as high as possible. To detect the overloaded cell, Call Blocking Ratio (CBR) is used as triggering mechanism. To minimize the load, optimization solution is implemented for unicast service and multicast service by selecting the proper transmission mode between Single Frequency Network (SFN) and Point to Multipoint (PTM) network. Moreover, to efficiently balance the congested cell detected by CBR Heaviest-First-Load-Balancing algorithm is implemented to avoid congestion in the traffic.

Keywords: Call blocking ratio, congestion, distributed, load balancing, LTE network, multi-class traffic, Ratio

INTRODUCTION

MIMO-LTE networks: In order to cope with the increased traffic demand, the 3rd Generation Partnership Project (3GPP) has developed the Long Term Evolution (LTE) standard for 4G cellular networks. This is based on Orthogonal Frequency Domain Multiplexing (OFDM) waveform for downlink (DL) and Single Carrier Frequency Domain Multiplexing (SC-FDM) waveform for uplink (UL) communications. The key objectives of LTE networks are user high data rates, reduced latency, improved system capacity and coverage, low complexity, reduced cost of operation and seamless integration with existing systems (Vajapeyam *et al*., 2011; Ronoh and Mengistie, 2012).

3GPP LTE networks can achieve high spectrum efficiency due to the usage of Multi-Input and Multi-Output (MIMO) antenna and Orthogonal Frequency Division Multiple (OFDM) technology. There are many MIMO schemes standardized in 3GPP systems and the base station scheduler has the capability to optimally select the MIMO scheme that suits the channel conditions of the mobile. A fundamental MIMO scheme is that of precoded Spatial Multiplexing (SM) where multiple information “streams” are transmitted simultaneously from the base station to the mobile. These techniques are appropriate in high SINR areas with rich scattering environments, in combination with suitable antenna configurations. However, the network performance is still influenced by several factors, among which Inter-Cell Interference (ICI) and load imbalance are two major ones (Li *et al*., 2012c).

Objective of the work: In Thirumalai and Vaitilingam (2015), SINR approximation and hierarchical CSI feedback technique was proposed for downlink multi user MIMO-LTE-A networks to improve the throughput. The main idea of hierarchical feedback is that if the channel is altered slowly, the channel state information feedback can be aggregated over multiple feedback intervals so that the aggregated bits index a larger codebook. There are pre-defined numbers of levels in a hierarchical codebook tree. This increased codebook size can effectively improve the performance of MU-MIMO.

During the transmission, congestion or overloading of data may occur. Load imbalance in LTE networks deteriorates the system performance influenced by unbalanced load distribution among nearby cells. Load balancing scheme is required to minimize the demanded radio resources of the maximum loaded cell to avoid the traffic congestion in LTE networks. Hence real-time inter-cell optimization is adaptable to environment especially when unbalanced and time varying, is needed.

Load Balancing is defined as an automatic way to resolve the overloading by shifting traffic towards the

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light-loaded cells, by making use of the radio resources more efficiently across the whole network. One possible way to balance the network load is to adjust the network control parameters in such a way that overloaded cells can offload the excess traffic to low-loaded adjacent cells, whenever available. However, this action might introduce additional handovers, which might cause bad handover performance, leading to the result that system would adjust handover parameters to reorganize the situation, which might be in contradiction to the aim of load balancing (Li *et al*., 2012c).

Hence we propose to develop a load balancing technique for mutli-user multi-class traffic in MIMO-LTE-A networks.

LITERATURE REVIEW

Li *et al*. (2012b) have proposed a dynamic hysteresis-adjusting. With this proposed method, the two SON aspects load balancing and handover parameter optimization can achieve a better coordination. The new method tunes the hysteresis according to a key indicator radio link failure ratio, with realistic consideration, thus avoiding the possibility that load balancing has a bad influence on the network performance, for example, causing a higher radio link failure ratio and risk of jeopardizing the normal function of a network. With the proposed method, which is simple and easy to realize, the network handover performance and load balancing effect are both guaranteed compared with conventional solutions. However there occurs handover failure.

Wang *et al*. (2010) have proposed network structure constraints and a practical suboptimal algorithm, called Heaviest-First Load Balancing (HFLB). Using the HFLB algorithm the network can get significantly better load balancing while maintaining the same network throughput at the price of a bit more handovers compared with the traditional signal strength-based handover algorithm. However the load balance index in mobile scenario is lower. And the radio resource consumption increases.

Min *et al*. (2012) have proposed a min-max Load Balancing (LB) scheme to minimize the demanded radio resources of the maximum loaded cell. For the mixed multicast and unicast services, multicast services are transmitted by Single Frequency Network (SFN) mode and unicast services are delivered with Point-To-Point (PTP) mode. The min-max LB takes into account Point-To-Multipoint (PTM) mode for multicast services and selects the proper transmission mode between SFN and PTM for each multicast service to minimize the demanded radio resources of the maximum loaded cell. Based on the solution of this minimization problem, if the maximum loaded cell does not overload, the min-max LB will change PTM mode into SFN mode for multicast services to achieve high Quality Of Service (QoS). The proposed min-max LB scheme requires less radio resources from the maximum loaded cell than SFN mode for all multicast services.

Bo *et al*. (2011) have proposed an inter-domain cooperative traffic balancing scheme focusing on reducing the effective resource cost and mitigating the co-channel interference in multi-domain Het-Net. The detailed implementation for the proposed traffic balancing scheme is designed. In the numerical evaluation, the Genetic Algorithm (GA) as an optimization method is used to demonstrate that the total effective resource cost is significantly reduced through their proposed inter-domain traffic balancing scheme comparing with the intra-domain traffic balancing scheme. The 43% of the resource cost is saved. The proposed scheme has great advantages in interference management in Het-Net. However the cell-edge throughput and the average cell throughput is not increased effectively.

Hao *et al*. (2013) have proposed a Mobility Load Balancing (MLB) as an important use case in 3GPP Self-Organizing Network (SON), in which the serving cell of a user can be selected to achieve load balancing rather than act as the cell with the maximum received power. In this study, a unified algorithm is proposed for MLB in the LTE network. The proposed algorithm is evaluated for users with different kinds of QoS requirements, i.e., Guaranteed Bit Rate (GBR) users with the objective function of load balance index and non-GBR (nGBR) users with the objective function of total utility, respectively. The proposed algorithm leads to significantly balanced load distribution for GBR users to decrease the new call blocking rate and for nGBR users to improve the cell-edge throughput at the cost of only slight deterioration of total throughput. However with the larger arrival rates the more will be unbalanced loading.

Li *et al*. (2012a) have proposed an LTE virtualization framework (that enables spectrum sharing) and a dynamic load balancing scheme for multi-eNB and multi-VO (Virtual Operator) systems. They compare the performance gain of both schemes for different applications, e.g., VoIP, video, HTTP and FTP. They also investigate the parameterization of both schemes, e.g., sharing intervals, LB intervals and safety margins, in order to find the optimal parameter settings. The LTE networks can benefit from both NV and LB techniques.

Altrad and Muhaidat (2013) have proposed a general load-balancing algorithm to help congested cells handle traffic dynamically. The algorithm is based on clustering methods and can be applied to any wireless technology such as LTE, WiMAX and GSM. The algorithm can be automatically controlled and

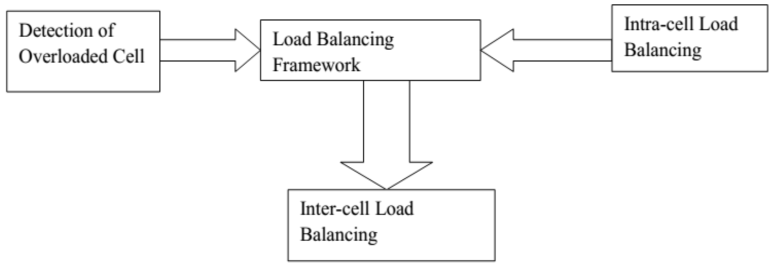

Fig. 1: Block diagram

triggered when needed for any cell on the system. It can be implemented in a distributed or semi-distributed fashion. The triggering cycle for this algorithm is left for the operator to decide on; the underlying variations are slow so there is no need for fast Self-Optimizing Network (SON) algorithms. The distribution of the load of the congested cell to its neighbor is one step only, which significantly reduces the signaling overhead and wasting of resources in the lightly-loaded cells compared to conventional methods.

PROPOSED SOLUTION

Overview: From the existing works, we can observe certain drawbacks, the handover failures in DHA (Li *et al*., 2012a), the load balance index in case of mobile scenarios decreases (Wang *et al*., 2010) the waste radio resources is saved for the unnecessary multicast services (Min *et al*., 2012), due to periodic data collection, Bo *et al*. (2011) leads to large-scale signal changes and signaling overhead, the handover (Li *et al*., 2012a) might cause packet loss problem, the reduction of congestion (Altrad and Muhaidat, 2013) is almost less.

We propose to design a load balancing framework with traffic balancing in LTE networks. A load balancing framework is developed (Wang *et al*., 2010) which balances the entire network load while keeping the network throughput as high as possible. Here by analyzing the complexity of the optimization problem, network structure constraints are presented and a practical suboptimal algorithm called Heaviest-First Load Balancing (HFLB) is proposed. The main objective of this framework is to make use of enforced handover to balance the load between different cells and keep the network throughput as high as possible at the same time.

Along with HFLB (Wang *et al*., 2010), the load minimization is applied in which the proper transmission mode PTP (point-to-point) is selected for unicast services in SFN (single frequency network) (Min *et al*., 2012). This minimizes the radio resources for the maximum loaded cells. For the detection of overloaded cells, Call Blocking Ratio (CBR) Altrad and Muhaidat (2013) is used as the triggering method. Then the algorithm based on load balancing is invoked into the congested cells (Wang *et al*., 2010).

Figure 1 represents the proposed block diagram. A load balancing framework is implemented to efficiently balance the load by detecting the overloaded cell and then minimizing the loaded cell. A suboptimal algorithm is proposed to efficiently balance the loaded cell.

Detection of overloaded cell: In order to detect the overloaded cells, Call Blocking Ratio (CBR) is the real parameter which indicates the degradation of the system when any overload occurs (Fig. 2). Here, m is detected as the overloaded cell. In our proposed solution, CBR is used as a triggering mechanism to enhance load balancing in LTE:

$$CBR \geq \tau \qquad (1)$$

where,
CBR = Blocked calls/total accepted calls.

Also, τ is predefined threshold reserved for operator use which is decided by the Quality Of Service (QoS) achieved by transmission mode of multicast services.

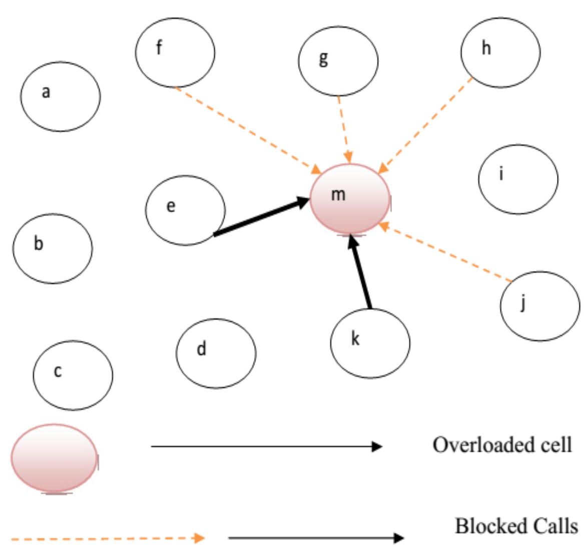

Fig. 2: Detection of overloaded cell

Inter cell load balancing using heaviest first load balancing: This section first describes about the detection of overloaded cell and the sub optimal algorithm that efficiently balance the load without affecting the throughput.

Definition of utility function: Given |E| eNodeBs and |N|mobile users, we first find an optimal assignment between mobile users and cells.

For this, first we define a utility function in the multi-cell network which is given as below:

$$V(\phi,\varphi)(t) = \phi P(t) - \varphi\mu(t) \tag{2}$$

where, $\phi \geq 0$ and $\varphi \geq 0$ are weighting coefficients on network throughput and load balance index respectively.

Different values of ϕ and φ in solving the joint optimization problem in Eq. (2) can suitably be selected between the tradeoff between load balancing and network throughput.

Since, $P(t)$ and $\mu(t)$ are both determined by the allocation between users and cells, the problem is to find the optimal allocation that maximizes $V(t)$ for the current timeslot t.

Let load at each cell i at time slot t is given by:

$$L_i(t) = bu(t)/b(t) \tag{3}$$

where, b(t) and bu(t) denotes the number of PRB and number of used PRB at cell i.

The average load of the network at time t is given by:

$$L1_i(t) = \sum_{i \in N} Li(t) / |N| \tag{4}$$

Then load balance index μ(t) can be given by:

$$\mu(t) = \sum_{i \in N} (Li(t) - L1i(t))^2 \tag{5}$$

Define an allocation indicator variable $I_{m,n}(t)$, which is equal to 1 when eNodeB m allocates a physical resource block (PRB) to user n at timeslot t or to 0 otherwise. Hence the load definition of cell m can be formulated as:

$$\eta_m(t) = \sum\nolimits_{n \in N} I_{m,n}(t)/b \tag{6}$$

Here b is the total number of PRB.

Representing the allocation by the matrix $I(t) = (I_{m,n}(t) : m \in E, n \in N, \forall t \geq 0)$, hence the problem is equivalent to the following maximization problem with I (t):

$$\max_{I(t)} V(I,\phi,\varphi)(t) = \phi P(I(t)) - \varphi\mu(I(t)) \tag{7}$$

$$\text{s.t} \sum_{n \in N} I_{m,n}(t) \leq b, \forall m \in N \tag{8}$$

$$\sum_{m \in N} I_{m,n}(t) = 1, \forall n \in N, \tag{9}$$

$$\sum_{m \in N} I_{m,n}(t) p_{m,n}(t) \geq \theta, \forall n \in N \tag{10}$$

where, $P(I(t)) = \sum\nolimits_{n \in N} \sum\nolimits_{m \in N} p_{m,n}(t) I_{m,n}(t)$ is the network throughput at the timeslot t.

$P_{m,n}$ (t) is the available Shanon rate at time slot t given by:

$$P_{m,n}(t) = W_{i,k} \log_2 + SNR_{i,k}(t) \tag{11}$$

Also, θ represents minimal throughput of each user.

The constraints in Eq. (8) represents that all cells have almost the same capacity limitation and also the number of user operated by one eNodeB can't exceed the number of its total PRBs.

Constraint in Eq. (9) represents that one user can only be operated by one eNodeB at some specific timeslot t.

Constraint in Eq. (10) represents that user can be operated by the eNodeB which can afford it a throughput value larger than the θ

Assuming that cell i handovers a user k to a target cell j for load balancing, the following condition should be satisfied:

$$u(j)' + u(i)' > u(j) + u(i) \tag{12}$$

where, u(j)' and u(i)' are the updated values of individual utility functions after handover for cell j and i, respectively.

Heaviest first load balancing algorithm: In each load balancing choose the heaviest loaded one whose load exceeds the threshold ρ to perform load balancing according to Heaviest-First Load Balancing which is described as below:

//At the mth load balancing cycle//

1. Each and every eNodeBs receive load status from its neighboring cells with CBR.
2. Cell m is the heaviest one.
3. If load of cell m exceeds threshold τ,

go to step5

Else

Stop

End if

5. In cell m, find user n and target cell c with the largest $y^n_{m,c}$.
6. If it satisfies inequality (11), then

Switch user n to cell c

Update other users' gain in cell m, then go to next step

Else
Stop
End if
7. If load status of cell m still exceeds threshold τ, then go to step 5.
Else
Stop
End if

Intra-cell load balancing: This section describes about the optimization solution for load balancing which aims at minimizing the demanded radio resources of the overloaded cells detected by the CBR.

Assume, M^* be the overloaded cell and R_{max} represents the demanded radio resources for the services in the cell M^*. Also, D_{M^*} represents the demanded radio resource for the unicast services and η_{M^*} be the set of the multicast services in the cell M^*. Hence, minimizing the demanded radio resources of the overloaded cell is formulated as below:

$$\begin{aligned} \min\ R_{\max} &= \min\Big(\sum_{j\in\eta_{M^*}} R_{M^*j} + D_{M^*} = \\ &\min\Big(\sum_{j\in\eta_{\min}} R_{M^*j} + \sum_{j\in\eta_{M^*},\, j\in\eta_{SFN}} R_{M^*j} + \sum_{j\in\eta_{M^*},\, j\in\eta_{PTM}} R_{M^*j} + D_{M^*} = \\ &\min\Big(\sum_{j\in\eta_{\min}} R_j + \sum_{j\in\eta_{M^*},\, j\in\eta_{SFN}} R_j + \sum_{j\in\eta_{M^*},\, j\in\eta_{PTM}} R_j + D_{M^*} \end{aligned} \tag{13}$$

where, D_{M^*} is constant for the unicast services in the cell M*. Since, $\sum_{j\in\eta_{\min}} R_j$ represents the minimum demanded radio resources for the multicast services in the set η_{min}, the key of minimizing R_{max} is specified as:

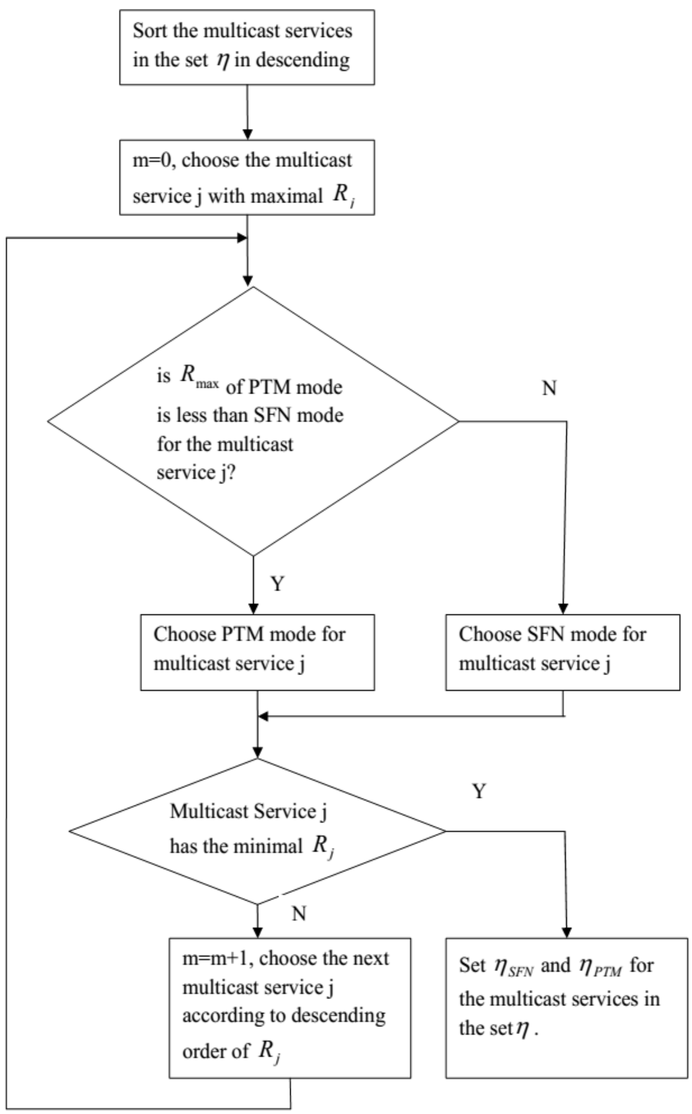

Fig. 3: Optimization solution for load balancing

$$\min\left(\sum_{j\in\eta_{M^*}, j\in\eta_{SFN}} R_j + \sum_{j\in\eta_{M^*}, j\in\eta_{PTM}} R_j\right) \quad (14)$$

The multicast services in the set η are sorted in the descending order of R_j, after that each multicast service choose the proper mode between Point to Multipoint (PTM) and Single Frequency Network (SFN) for less demanded radio resources. Since, SFN mode gains higher QoS for multicast service j than PTM mode with the same R_j, η_{SFN} and η_{PTM} are set based on minimum R_{max} and high QoS as:

$$\begin{cases} j \in \eta_{SFN} \ ; j \in \eta_{M^*} \\ j \in \eta_{PTM} \ ; j \notin \eta_{M^*} \end{cases} \quad (15)$$

It is important to note that η_{SFN} and η_{PTM} is determined on the less R_{max} where the dispute of selecting SFN mode and PTM mode for multicast service j breaks out. In case, R_{max} of SFN mode is equivalent to that of PTM mode, hence the SFN mode is to be selected for higher QoS. The optimization algorithm is explained as below:
The optimization solution is represented in Fig. 3.

Step 1: Sort the multicast services in the set η in descending order of R_j
Step 2: Estimate R_{max} by the two different transmission mode of SFN and PTM for multicast service with the maximal R_j.
Step 3: Compare both modes.
Step 4: Set $j \in \eta_{PTM}$ when R_{max} of PTM mode is less than that of SFN mode.
Step 5: When R_{max} of the two modes are equal, set $j \in \eta_{SFN}$.
Step 6: Based on sorting done in step 1, select the proper mode between SFN and PTM by same condition of step 2.
Step 7: Set η_{SFN} and η_{PTM} for the multicast services in the set η.

The overall proposed algorithm:
// Initiation of Load balancing framework//
1. Define utility function
2. Define allocation indicator variable
3. Define maximization problem.
// Detection of overloaded cell//
4. Define CBR
5. Compare with τ
6. If $CBR \geq \tau$
7. Then consider cell as overloaded.
// Optimization Solution for Overloaded Cell //
8. Sort the multicast services in the set η in descending order of R_j
9. Estimate R_{max} by the two different transmission mode of SFN and PTM for multicast service with the maximal R_j.
10. Compare both modes.
11. Set j ∈ η_{PTM} when R_{max} of PTM mode is less than that of SFN mode.
12. When R_{max} of the two modes are equal, set $j \in \eta_{SFN}$.
13. Based on sorting done in step 8, select the proper mode between SFN and PTM by same condition of step 9.
14. Set η_{SFN} and η_{PTM} for the multicast services in the set η.
//At the mth load balancing cycle//
15. Each and every eNodeBs receive load status from its neighboring cells with the CBR.
16. Cell m is the heaviest one.
17. If load of cell m exceeds threshold τ , go to next step
18. Else stop.
19. In cell m, find user n and target cell c with the largest $y^n_{m,c}$.
20. If it satisfies inequality of Eq. (12), then switch user n to cell c
21. Update other users' gain in cell m, then go to next step
22. Else stop.
23. If load status of cell m still exceeds threshold τ,
24. Then go to step 19.
25. Else stop.

SIMULATION RESULTS

Simulation model and parameters: The Network Simulator (http:///www.isi.edu/nsnam/ns) NS-2, is used to simulate the proposed architecture. In the simulation, 50 mobile nodes move in a 1200 m×1200 m region for 50 sec of simulation time. All nodes have the same transmission range of 250 m. The simulated traffic is Constant Bit Rate (CBR). The simulation topology is shown in Fig. 4.

The simulation settings and parameters are summarized in Table 1.

Performance metrics: The proposed Distributed Load Balancing for Multi-user Multi-class Traffic (DLBMM) is compared with the HFLB technique (Wang *et al*., 2010). The performance is evaluated mainly, according to the following metrics:

- **Packet delivery ratio:** It is the ratio between the number of packets received and the number of packets sent
- **Packet drop:** It refers the average number of packets dropped during the transmission
- **Received bandwidth:** It is the number of mega bits received per second

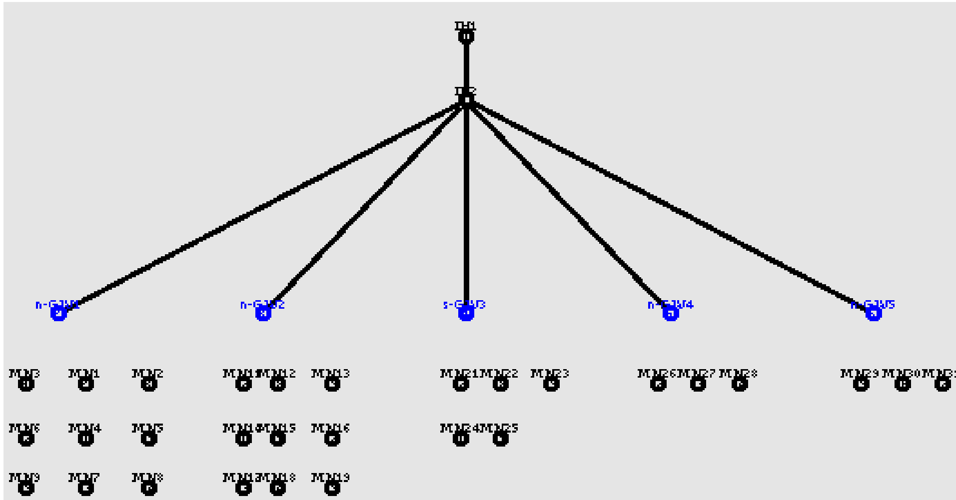

Fig. 4: Simulation topology

Table 1: Simulation settings

No. of Nodes	31
Area Size	1200 X 1200
Mac	IEEE 802.11
Transmission Range	250 m
Simulation Time	50 sec
Traffic Source	CBR, Exponential and Video
Packet Size	512
Rate	1,1.5, 2, 2.5 and 3Mb
Initial Energy	4.1J
Transmission Power	0.660
Receiving Power	0.395
Idle Power	0.035

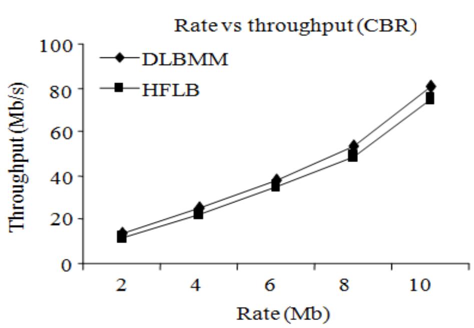

Fig. 5: Rate vs received bandwidth

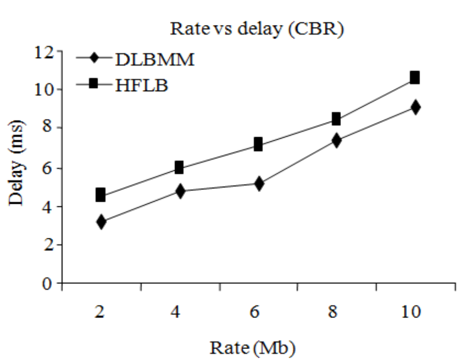

Fig. 6: Rate vs delay

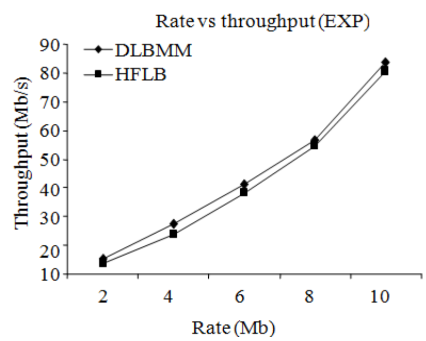

Fig. 7: Rate vs delivery ratio

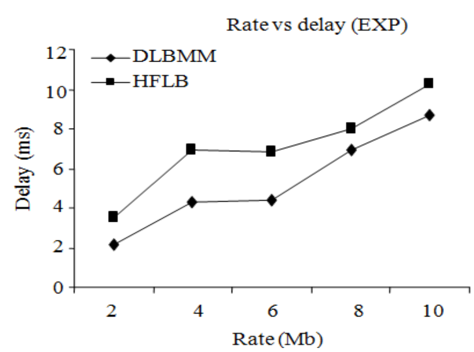

Fig. 8: Rate vs packet lost

- **Delay:** It is the amount of time taken by the nodes to transmit the data packets.

Results: Here the load of cell-1 is balanced among the cells 3 and 4. The transmission rate is varied as 1, 1.5, 2, 2.5 and 3Mb and the above performance metrics are evaluated at cell-1 for downlink CBR and Exponential traffic.

Case-1 For CBR traffic: Figure 5 to 9 show the graphical representation of the results for Bandwidth

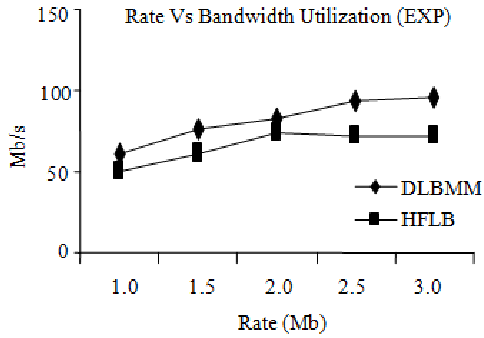

Fig. 9: Rate vs received bandwidth

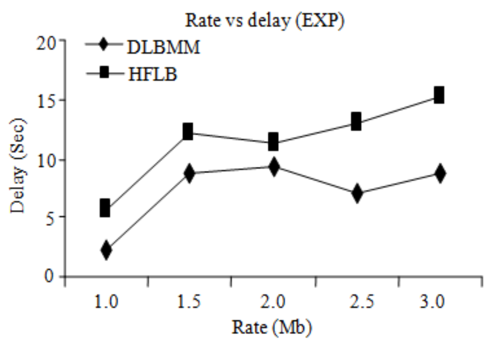

Fig. 10: Rate vs delay

utilization, delay, packet delivery ratio and packet drop for Constant Bit Rate (CBR) traffic scenario.

Because of the distributed load balancing and optimization in DLBMM, the overloaded traffic is evenly distributed, there by reducing the packet drop and improving the bandwidth utilization. Hence from the figures, we can see that DLBMM outperforms HFLB in terms of bandwidth utilization by 42%, delay by 33%, packet delivery ratio by 39% and packet drop by 21%.

Case-2 For exponential traffic: Figure 10 to 14 show the graphical representation of the results for Bandwidth utilization, delay, packet delivery ratio and packet drop for exponential traffic case scenario.

Because of the distributed load balancing and optimization in DLBMM, the overloaded traffic is evenly distributed, there by reducing the packet drop and improving the bandwidth utilization. Hence from the figures, we can see that DLBMM outperforms HFLB in terms of bandwidth utilization by 19%, delay by 39%, packet delivery ratio by 18% and packet drop by 44%.

Case-3 For video traffic: Figure 13 to 16 show the graphical representation of the results for Bandwidth utilization, delay, packet delivery ratio and packet drop for video traffic scenario.

Because of the distributed load balancing and optimization in DLBMM, the overloaded traffic is

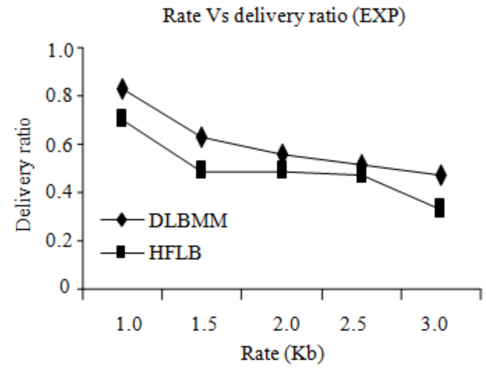

Fig. 11: Rate vs delivery ratio

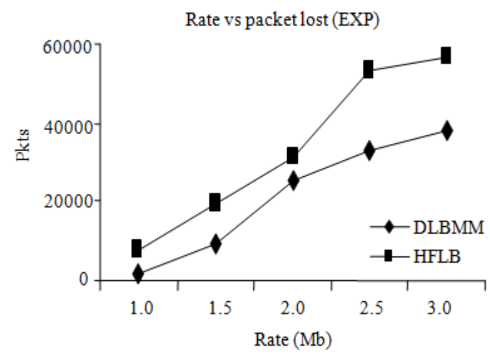

Fig. 12: Rate vs packet lost

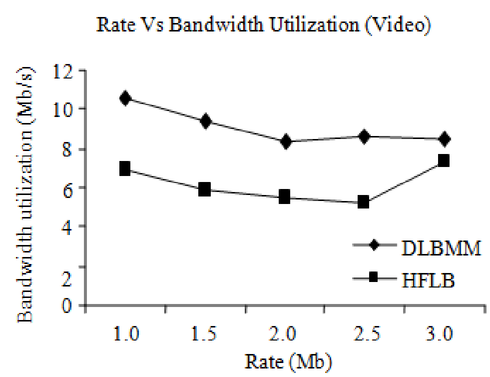

Fig. 13: Rate vs bandwidth utilization

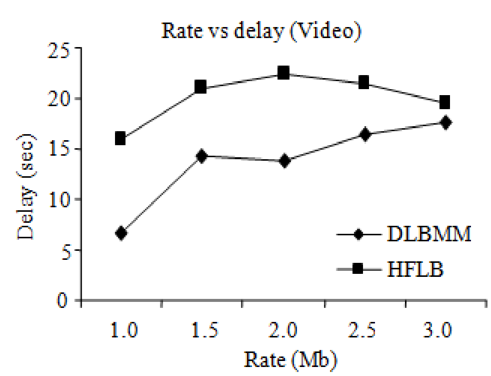

Fig. 14: Rate vs delay

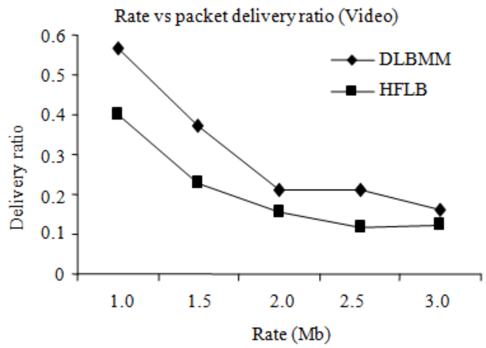

Fig. 15: Rate vs delivery ratio

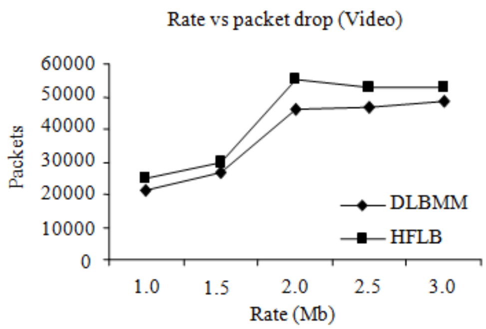

Fig. 16: Rate vs packetdrop

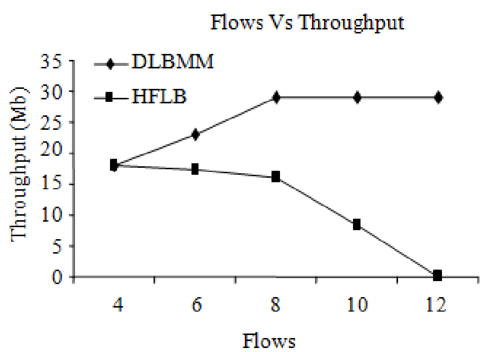

Fig. 17: Flows vs throughput

evenly distributed, thereby reducing the packet drop and improving the bandwidth utilization. Hence from the figures, we can see that DLBMM outperforms HFLB in terms of bandwidth utilization by 32%, delay by 32%, packet delivery ratio by 33% and packet drop by 15%.

Throughput for varying flows: Figure 17 shows the cumulative throughput obtained for all types of traffic when the number of traffic flows is increased from 4 to 12.

As we can see from the figure, for 4 flows, the both DLBMM and HFLB attains the same throughput. But beyond, 6 flows, the throughput of HFLB begins to reduce and becomes zero at 12 flows, since the blocking probability of the overloaded cell will be more. On the otherhand, DLBMM maintains constant throughput of 28 Mb upto 12 flows which is 48% higher than that of HFLB.

CONCLUSION

In this study, we have proposed a Distributed Load Balancing for Multi-user Multi-class Traffic in MIMO-LTE Networks. A robust load balancing framework is implemented that efficiently handles the overloaded traffic and also keep the throughput as high as possible. CBR is used to detect the overloaded cell that detects the load as soon as the service degradation happens. In order to minimize the load, a optimization solution is implemented by selecting proper transmission mode between SFN and PTM network. In order to efficiently handle the congested cell detected by CBR, Heaviest-First-Load-Balancing algorithm is implemented to avoid any kind of congestion in the network.

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