2018 5th IEEE Uttar Pradesh Section International Conference on Electrical, Electronics and Computer Engineering (UPCON)

Optimization of Capacity Allocation Problem in 4G LTE Mobile Networks

Rajalakshmi Krishnamurthi
Department of Computer Science,
Jaypee Institute of Information Technology, Noida
k.rajalakshmi@jiit.ac.in

Mukta Goyal
Department of Computer Science,
Jaypee Institute of Information Technology, Noida
mukta goyal@jiit.ac.in

Abstract: - In today's information era, the mobile communication has outperformed as one of the leading technology for information exchange. It is highly possible, by mobile networks to provide any time and any where communication strategy, which meets the user requirements. However, the rising demand for multimedia, interactive and high quality of services on mobile network platform has made the existing mobile technologies to be reconsidered and reengineered. The 4G technology is one such platform that addresses the challenges in conventional mobile communication network. In this regard, 4G Long Term Evolution (4G -LTE) has promised to be effective solution to meet the future challenge of dynamism in all dimension of mobile communication. This work primarily focuses on reviewing the LTE mobile technology, the various challenges in designing LTE network and the issues in LTE while performing intended operations. Specifically, in LTE network design, the optimization of capacity allocation in LTE backhaul network is one of the most challenging issues due to high dynamic nature of mobile network communications and components. Such optimization problems are hard to solve in polynomial time. Next, this work addresses the reduction of LTE capacity allocation problem as NP complete using subset sum problem. Further, adaptive iterative local search algorithm is proposed to solve this problem. The experimental results exhibited the efficiency of proposed algorithm as 67% improvement in computation time in comparison of greedy method.

Keywords: *mobile networks, 4G technology, Long Term Evolution, optimization problem, subset sum problem, NP complete.*

I. Introduction

The 4G also known as 4th generation technology is the convergence platform for all existing network technologies like 2G, 3G, Wireless Local Area network (WLAN), WiMAX, Wireless Personal Area Network (WPAN), and including wired network systems [1,2]. In addition, 4G is the advancement and integration of existing protocols like GSM, GPRS, EDGE, UMTS, W-CDMA, CDMAone, IMT-2000, WiFi, Zigbee , Bluetooth, etc [3]. The major goal of the 4G technology is to provide end to end best quality of multimedia, interactive services over Internet Protocol. However, the challenging issue is, any 4G system must provide capabilities defined by ITU (International Telecommunications Union) in IMT (International Mobile Telecommunications) Advanced [4, 5].

The 4G-LTE network is one such kind of mobile communication network that exhibits potential solution to achieve the goals set by ITU-IMT. The notable technological advancement in 4G-LTE is that, the removal of redundant circuit switching based data transmission [6, 7]. To recollect, in conventional 2G network, the voice traffic is transmitted through Mobile Switching Centres (MSC) as TDMA frames by base stations. However, in 4G-LTE all these, voice traffic are converted into data packets at base station and is transmitted as Voice over Internet Protocol (VoIP) through IP backhaul network. Next major milestone in 4G-LTE network is that, the 4G mobile network is completely in conjunction with Wireless LAN, in oppose to the traditional way of wired LANs [2]. This way, the standards are been promoted for the air interfaces of 4G cellular network to integrate with wireless LANs. This technological evolution has out shown several advantages like support for high definition multimedia applications, enhanced mobility management, uninterrupted services, and diversified access network support through mobile networks.

The basic architecture of LTE mobile network is given below Figure 1. There are three major components involved namely Evolved Node Base Stations (eNBs), Evolved Pocket Core (EPC) and Network Resource Manager (NRM). The transmission link between eNBs and EPC are using any of the technologies like microwave, wireless, copper wired and optical links.

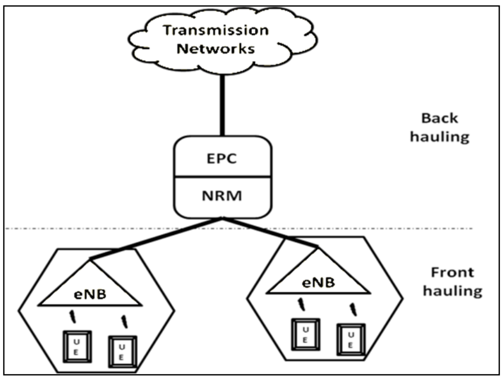

Figure 1. Basic architecture of LTE mobile network

The eNBs provide requested frequency by its various user equipments (UE). Other words, use equipment establish mobile communication through eNBs. The eNBs are controlled by network resource managers. The NRM allocate available total capacity to all its associated eNBs. Each EPC has its own NRMs. EPC is further connects to IP based 4G transmission networks. The main role of NRM is

978-1-5386-5002-8/18/$31.00 ©2018 IEEE

to perform network control, sharing available capacity and allocated capacity for dynamic requests from its associated eNBs.

Primarily, this work focuses to analyse various LTE backhaul network complexities. Further, in real mobile network scenario, these problems are hard optimization problems due to dynamic nature of network components, user mobility, and dynamic requirements of the end users. Hence, this optimization problem cannot be solved in deterministic way. In turn, prospective methods require intelligent ways to find solution for these problems. As stated in [1], the main objective of such optimization problem is to minimize the CAPEX/OPEX cost involved in LTE backhaul network. Further, this work focuses on, to show that the optimization problem at LTE backhaul capacity allocation is a NP complete.

II. Related Work

The LTE based mobile communication network has two levels of networking namely front hauling and backhauling. ***LTE Front hauling:*** At the state of art, several existing research literatures mostly address LTE front hauling networks. LTE front hauling network design targets spectrum allocation between eNBs and user devices [2, 3]. The communication link between eNBs and user devices is based on wireless medium. The objective at front haul network is the optimal frequency spectrum allocation for the user equipment to establish communication with suitable eNBs. The objective is further complicated by the signal propagation features of wireless communication along with dynamic nature of user and user requirements. In [8], discussed the capacity assignment using queuing methods for PON based mobile front haul network.

LTE backhauling**:** Next level is, the LTE backhaul network dealing with capacity allocation by EPC for eNBs. Authors in [9], addressed that the LTE backhaul network problem in two ways namely centralized approach and decentralized approach. The centralized approach for handling base station equipments is very expensive in case of backhauling network because of technical constraints like fixed available data transmission rate and heavy cost on latency. In case of distributed approach for handling backhaul network, might be cost efficient. However, the issues like interconnection, integration and management of difference technologies itself difficult to handle. In addition to this, another critical issue is interference problem between communication subcarriers.

The major hurdle and overstated in LTE backhauling network is available capacity at EPC. In reality, the available LTE capacity is limited and fixed per macrocell coverage. In [9], stated that the capacity is independent of number of subscribes per cell site or number of user equipments request connectivity. The complexity is further increased while more cell sites are added, which would in turn increase the mobile network operational and maintenance costs. Hence, the mobile service provides are in urge to plan and design cost effective backhaul methodologies. And the objective is to have optimized and balanced allocation of capacity among eNBs that servers high and dynamic user demand. Definitely, the LTE backhaul network has to fulfil critical requirement of flexible capacity in this evolving mobile communication network.

III. Optimization at LTE Backhaul Networking

The objective function targeted is, to optimally assign the available capacity at EPC, and serve the requested capacity of each associated eNBs. While satisfying the technical constraints that each eNB is associated with only one EPC at any given time. Further, the total allocated capacity of each eNBs should not exceed the available capacity of EPC. Also, the power allocated for each eNB should not exceed the total power available at EPC. In literature, this optimization problem is modelled using mathematical program like mixed integer problem for 2G, 3G mobile network [11, 12, 13].

Notations

N_u	Total number of users in LTE network
N_c	Total number of NRM subcarriers of EPC available in LTE network
i	End device *i* that belongs to set Nu
j	NRM Subcarrier *j* that belongs to set N_c of EPC
R	Maximum capacity of LTE NRM to end devices
r_i^j	On demand capacity rate by user *i* on LTE NRM subcarrier j
α	Residual capacity of available at EPC
P	Total power allocated to each eNB of LTE
p_i^j	Power required by end device *i* on LTE NRM subcarrier *j* of EPC.
β	Residual power of available at EPC
f_i^j	Flow matrix between eNB and the NRM of EPC in LTE

The objective function for the optimization of capacity allocation is defined by minimization function (min *F*), that performs assigning optimal data rate (r_i^j) for an existing flow (f_i^j) between eNB i and NRM of EPC j, while satisfying technical constraint of link allocation, capacity allocation and power allocation.

$$min\, F = \sum_i^{N_u} \sum_j^{N_c} r_i^j f_i^j \text{-------------------} \qquad (1)$$

Subject to

$$\sum_i^j R - r_i^j \le \alpha \quad \forall\, i \in N_u\,; \forall\, j \in N_c \;\; \text{------} \;(2)$$
$$\sum_i^j P - p_i^j \le \beta \quad \forall\, i \in N_u\,; \forall\, j \in N_c \;\; \text{--------} (3)$$
$$\sum_i^j f_i^j = 1 \quad \forall\, i \in N_u\,; \forall\, j \in N_c \;\; \text{------------} \;\; (4)$$

The capacity constraint, as stated in equation (2), defines that the sum of all the capacity r_i^j allocated to each eNB that are connected to EPC j must be within lower bound residual capacity (α) of total capacity R of the EPC.

Purpose of this capacity constraint is to balance the available capacity at the EPC and avoid overloading of a particular EPC, by distributing the total capacity among different eNBs and also across all EPC of LTE network. The power constraint, as given in equation (3), defines that the power allocated to each eNB *i* is within the lower bound of total power available at ENB *j*.The link constraint , as given in equation (4), defines that each eNB *i* is allocated to only one EPC resource of LTE network.

IV. LTE Capacity allocation problem and NP completeness

We define the problem as set of Evolved Packet Core (EPC) which is having a collection of call capacity requests from various evolved node base stations (eNBs). Each eNB should be under single EPC at any given time as shown Figure 2 below.

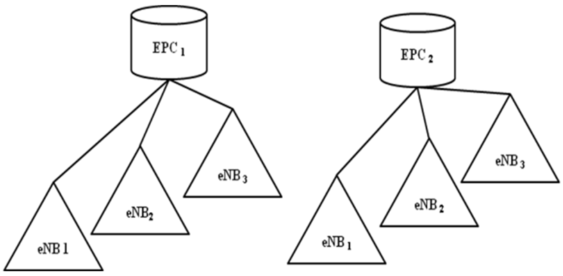

Figure 2. LTE capacity allocation approach

Problem formulation

For each call capacity request of eNB, we can easily determine the capacity request of each eNB. This is achieved, by abstracting each call capacity requests simply as an integer – the capacity of the requested eNB. The load which is exactly the capacity of the requested eNB stations that each EPC can accommodate is NP hard. Formally we define a S' is the entire set of module which represent the EPC and the eNBs. We define a partition between EPC's and eBNs as two set of modules that cover all eNB nodes.

Theorem 1: *The load which is exactly the capacity of the requested base stations that each EPC can accommodate is NP hard.*

Proof: Let the capacity handled by EPCs be B. The set of base stations be S. $S = \{k_1, k_2, k_3 \ldots\ldots k_n\}$ where $k_1, k_2, \ldots\ldots k_n$ are capacity of the eNB base stations.

Now since we are given that the capacity is exactly equal to the load. Thus we will have a subset S' in S. Such that $\sum_{i=1}^{m} S'$ = B. Here B is the capacity of EPC.

We can assume that the new set as $S - S'$. Allocating the EPC until we get $\sum S = B$ i.e. Subset Sum problem.

Now we reduced the given problem into subset sum problem. If subset sum problem is NP complete then this is also NP complete.

To prove subset sum problem is NP complete. Assume

$$\varphi = C_1 \wedge C_2 \wedge C_3 \wedge C_4$$
$$C_1 = (x_1 \vee \overline{x_2} \vee \overline{x_3})$$

$$C_2 = (\overline{x_1} \vee \overline{x_2} \vee \overline{x_3})$$
$$C_3 = (\overline{x_1} \vee \overline{x_2} \vee x_3)$$
$$C_4 = (x_1 \vee x_2 \vee x_3)$$

Let t be the desired sum of (n+k) bits. If we have an independent set S' such that $\sum S' = t$ then subset sum is NP-complete. Reducing 3SAT to subset sum is shown in Table-1

Where $y_1 = x_1, z_1 = \overline{x_1}, s_1 = c_1, s_1' = \overline{c_1}$

We have y_1, y_2, z_3, s_2, s_3' as independent sets. Now subset sum is NP complete. Therefore the problem is also NP complete.

Let x represent the load to compute on each then $x = \frac{\sum(bandwidth)}{B_{max}\ of\ EPC}$. If we increase base stations, the load on EPC's increase until $B_{\max(x)} = \sum(bandwidth)$, after which an EPC is increased. As we increase EPCs, the load across each EPC will decrease. Hence the proof.

Table 1. Reducing 3SAT variables to subset sum variables

	x_1	x_2	x_3	c_1	c_2	c_3	c_4
y_1	1			1			1
z_1					1	1	
y_2		1					1
z_3		1		1	1	1	
y_3			1			1	
z_3			1	1	1		
s_1				1			
s_1'				1			
s_2					1		
s_2'					1		
s_3						1	
s_3'						1	
s_4							1
s_4'							1
Total	1	1	1	2	2	2	2

V. ADAPTIVE ITERATIVE LOCAL SEARCH ALGORITHM [AILS]

The iterative local search algorithm developed by Thomas Stuzle in 1999, is a meta heuristic algorithm [10]. The techniques involved within ILS algorithm are simple and effective. In this paper, we used an incremental improvement to this basic ILS using adaptive local search method. The other effective operators are namely perturbation, shuffling limit and acceptance criteria. These method are simple to implement and powerful by converging within less computation item into feasible solution space. Hence, the adaptive ILS is well suitable to solve the NP hard capacity allocation problem in LTE Network.

The proposed AILS, takes input such as number of eNB (N_u), number of EPC (N_c), flow matrix (f_i^j), capacity matrix (r_i^j) and power matrix(p_i^j). Further, the constraints like link, capacity and power are provided as input into the system. Next, the objective function *(F)* to find the optimal capacity is coded into the system. The purpose of objective function (F) is produces optimal solution vector, with each eNBs assigned to the feasible EPC, while satisfying all technical constraints.

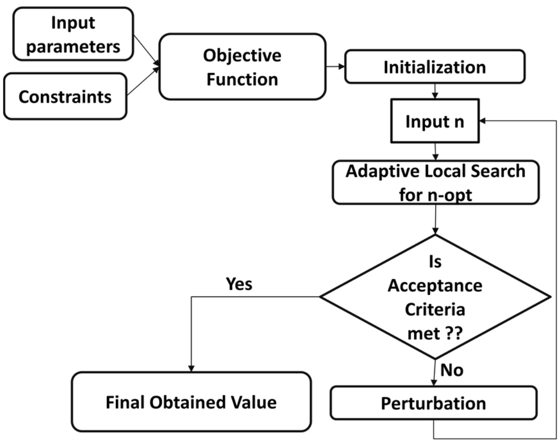

Figure 3. Block Diagram of Adaptive Iterative Local Search Heuristics Algorithm

During initialization phase, the random assignment of eNB to EPC is performed. This initialization using randomness is provided as input to next step, local search method. During initialization the objective function is estimated and acts as the upper bound for further feasible solutions within the search space of valid solution.

Next, the local search method is added with option for algorithm to choose between different neighbourhood solutions by exchanging values at some random locations within the allocation solution vector. In [10], details about different opt method for local search namely 2-opt, 3-opt, and 4-opt. In this work, the user can set the algorithm to choose different local search methods, hence is adaptive. These search operation are controlled by two powerful operators namely perturbation and acceptance criteria. In order to handle the feasible solution get stuck into the local search, perturbation operator is used.

The perturbation operator performs random shuffling of values in the current solution vector. Here, the local search is allowed to explore other solution spaces by pushing the local solution to away from current best local minima. The shuffling limit controls the perturbation process. The second, operator is acceptance criteria. The acceptance criteria, always measures whether the current local solution is better than the best known solution so far. Finally, the algorithm terminates once the iteration limit is reached.

VI. RESULTS AND DISCUSSION

The experiment was conducted on Intel (R) core(TM) i5-600 CPU at the speed of 3.2GHz, installed random access memory of 8GB, along with 64-bit operating system of x64 processor. Microsoft Visual C++ was used for programming the proposed iterative local search algorithm to solve capacity allocation in LTE network.

The inputs to the proposed adaptive local search algorithm are, N_c X N_u dimensional matrix for, capacity requirement matrix (r_i^j), flow matrix (f_i^j) and power matrix (p_i^j) . The capacity and power requirements are obtained using uniform distribution of random numbers between (1,100). The flow matrix is a binary matrix , in which 1 represents the existing flow between eNB_i and EPC_j and zero represents there exists no flow between eNB_i and EPC_j.

The Figure 4 depicts the obtained value in LTE network of 15 eNB with 2 EPC. It is observed that, the algorithm convergence to the optimal solution is achieved with in limited iteration.

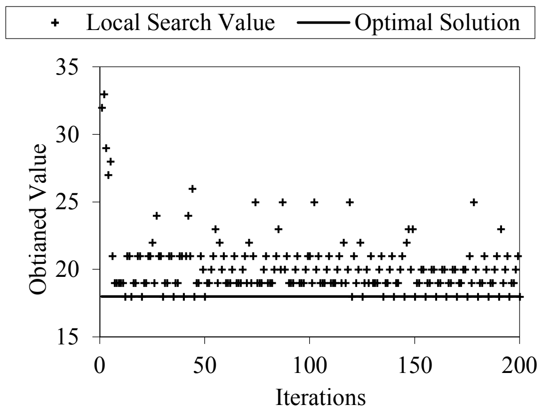

Figure 4. Objective function value obtained in 15 eNBs, 2 EPCs of LTE network for different iterations

The Table 2 represents the computation time for each of the different local search methods of proposed adaptive iterative local search algorithm.

It is observed that, the algorithm has exhibited very less time in comparison with greedy method of solving the capacity allocation problem. Improvement of 6.7% is achieved in computation time as shown in Table 2. Further, the algorithm exhibits there is significant time difference between the different local search executions.

Table 2 Computation Time for different local search options

No. of eNB (N_c)	No. EPC (N_u)	Greedy Method Time(sec)	AILS /2-opt time (ms)	AILS/ 4-opt time (ms)
50	2	2.15	170.318	163.43
	3	2.768	173.642	170.12
	4	2.890	185.094	181.52
	5	2.910	191	187.66
	6	3.451	195.84	190.80
100	2	3.159	782.504	778.66
	3	4.672	882.91	866.63
	4	5.133	894.07	882.31
	5	5.999	936.946	921.57
	6	6.014	965.884	947.05
200	2	7.343	3204.008	3151.31
	3	8.234	3587.69	3521.31
	4	8.32	3796.071	3731.46
	5	8.543	3933.946	3868.88
	6	9.654	3964.884	3893.45

VII. Conclusion

The 4G-LTE mobile network technology is one of the highly potential advancement to meet the requirements of ITU-IMT proposal. The 4G- LTE achieves its various requirements by technology enhancement, as well efficient ways to serving dynamic user demands. However, the achieving the goal has severe hurdles and stringent reality factors like available frequency spectrum, sharing of the available spectrum and allocation of available spectrum optimally among network components. This work, discusses the LTE technology, network components, the component functionalities, and various challenges. Specifically, the capacity allocation of LTE backhaul network is NP complete. In this work, the reduction of capacity allocation at LTE backhaul networking is stated and proved. Further, the proposed Adaptive Iterative Local Search Algorithm has exhibited improvement of average computation time by approximately 6.7% in comparison to greedy algorithm.

References

[1] F. Baccelli, N. Bambos and N. Gast, "Distributed Delay-Power Control Algorithms for Capacity Sharing in Wireless Networks," in *IEEE/ACM Transactions on Networking*, vol. 19, no. 5, pp. 1458-1471, Oct. 2011.

[2] Derrick Wing Kwan Ng, Ernest S. Lo, and Robert Schober, "Energy-Efficient Resource Allocation in Multi-Cell OFDMA Systems with Limited Backhaul Capacity", IEEE Transactions On Wireless Communications, Vol. 11, No. 10, October 2012.

[3] J. Liu, N. Kato, J. Ma and N. Kadowaki, "Device-to-Device Communication in LTE-Advanced Networks: A Survey," in *IEEE Communications Surveys & Tutorials*, vol. 17, no. 4, pp. 1923-1940, 2015.

[4] E-UTRA; MAC Protocol Specification. 3GPP TS 36.321.

[5] V. Osa, C. Herranz, J.F. Monserrat, X. Gelabert, “Implementing opportunistic spectrum access in LTE-advanced”, EURASIP Journal of Wireless Communications and Networking, vol. 2012, no.1, pp. 99 - 112, March 2012.

[6] “Mobile Backhaul Equipment, Installed Base and Services Market Outlook,” *Infonetics Research*, Oct. 2006.

[7] A. Asheralieva, "Prediction based capacity allocation for cognitive LTE network," 2013 IEEE Wireless Communications and Networking Conference (WCNC), Shanghai, 2013, pp. 801-806.

[8] W. Lim, P. Kourtessis, K. Kanonakis, M. Milosavljevic, I. Tomkos and J. M. Senior, "Dynamic Capacity Allocation in Heterogeneous OFDMA-PONs Featuring Intelligent LTE-A Traffic Queuing," in IEEE Journal of Lightwave Technology, vol. 32, no. 10, pp. 1877-1885, May15, 2014.

[9] H. Raza, "A brief survey of radio access network backhaul evolution: part II," in IEEE Communications Magazine, vol. 51, no. 5, pp. 170-177, May 2013.

[10] Stutzle, Thomas, “Local Search Algorithms for Combinatorial Problems – Analysis, Algorithms and New Applications”, Disseration an der Technischen Universitat Darmstadt, Berlin, 1999.

[11] Rajalakshmi, K., and Hima Bindu, M., “On Cost-efficient Optimization of UMTS Access Subsystem using Extended Evolutionary Heuristic Algorithm”, International Journal of Mobile Network Design and Innovation, Inderscience Publications, Vol. 4, No. 3 pp. 130 - 137 , 2012.

[12] Rajalakshmi, K. and Krishna Gopal, “Dual Homing based Link Level Failure Recovery in Mobile Access Network”, International Journal of Advanced Science and Technology, SERSC publications,Australia Vol.79, pp.1-14, June 2015.

[13] K. Rajalakshmi, Prakash Kumar, Hima M. Bindu, “Targeting Cells to switch assignment of Cellular mobile network using heuristic algorithm”, 14th WSEAS international conference on Computers, vol. 1, pp: 75-80, USA, July 23-25, 2010.