Introduction to my PhD Works

Multi-band Communication

Husnu S. Narman

Outline

- Introduction
- Objective
- Multi-band in Wi-Fi
- Multi-band in LTE-A
- Conclusion

Communication

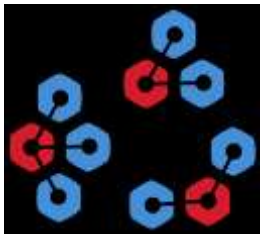
- A process by which information is exchanged between individuals (machines) through a common system of symbols, signs, or behavior

Multi-band Communication

- Using a number of different frequencies to communicate.
  - e.g. 2.4 GHz and 5 GHz

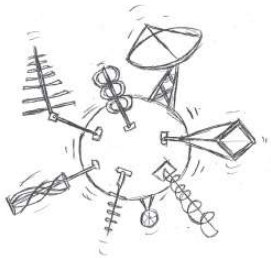
Factors of Multi-band Communication[1]

- Devices
  - Different devices (support single or multi band)
- Users
  - User profile (Teenager, businessman) and number of users
- Data
  - Data types (real time, non-real time)
- Bands
  - Characteristic of bands (e.g. 5 GHz - Higher data transfer rate (bandwidth) with lower range)



Challenges

- Antenna design issues[2][3]
  - Cost, space, interference

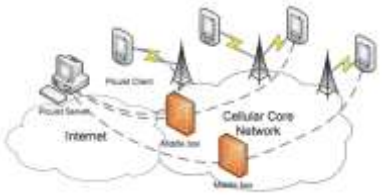


- Channel deployment[4]

- Routing[4]
  - Wireless mesh networks
- Resource (band and channel) allocation[1][5][6]
  - With scheduling and management

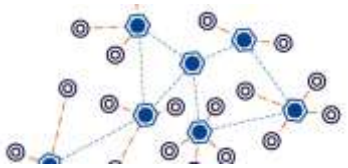
Applications of Multi Band Communication

- Cellular networks
  - LTE-A[7]



- Personal/Local area networks
  - Wi-Fi (802.11n)[8]

- Sensor networks[4]

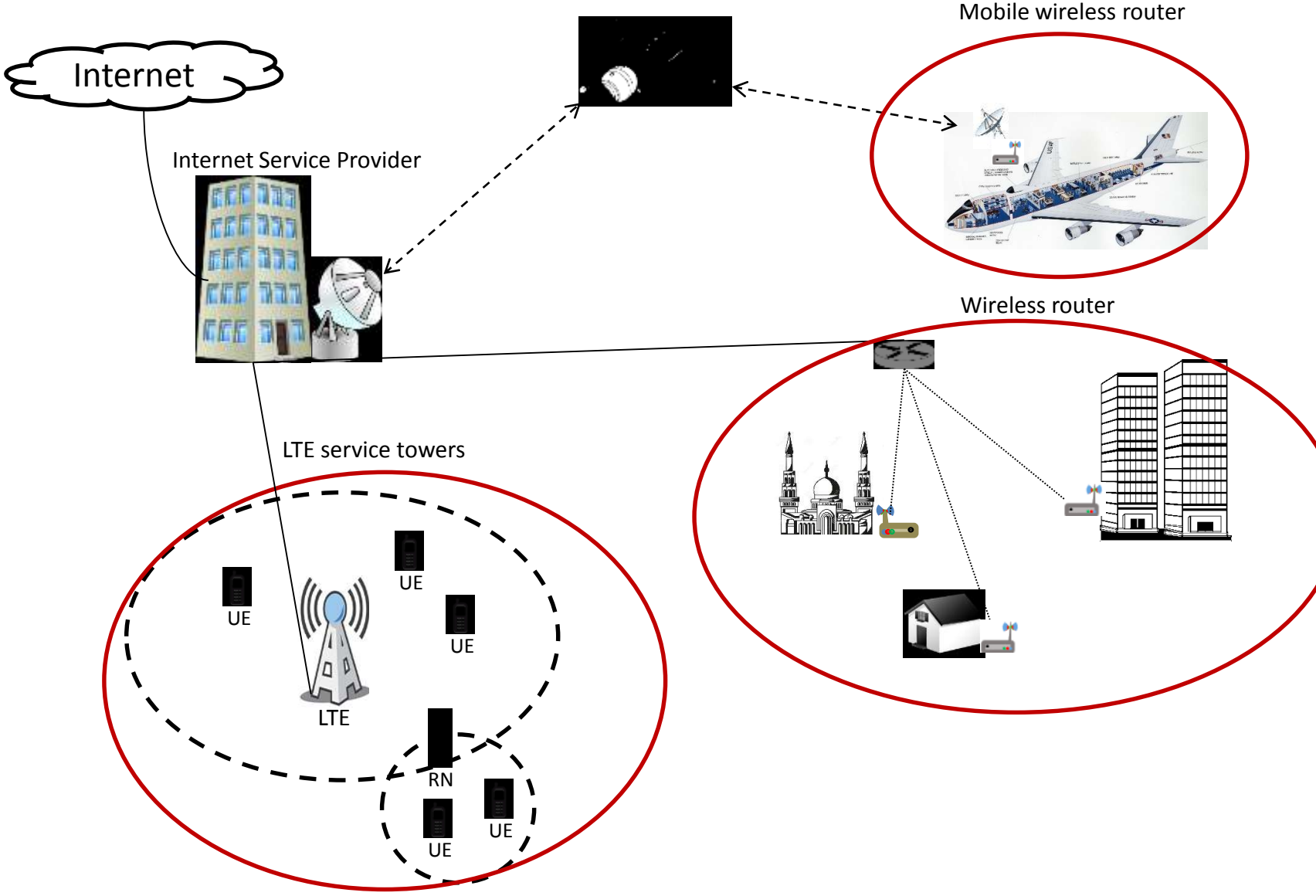


- Radar[9]

Objective

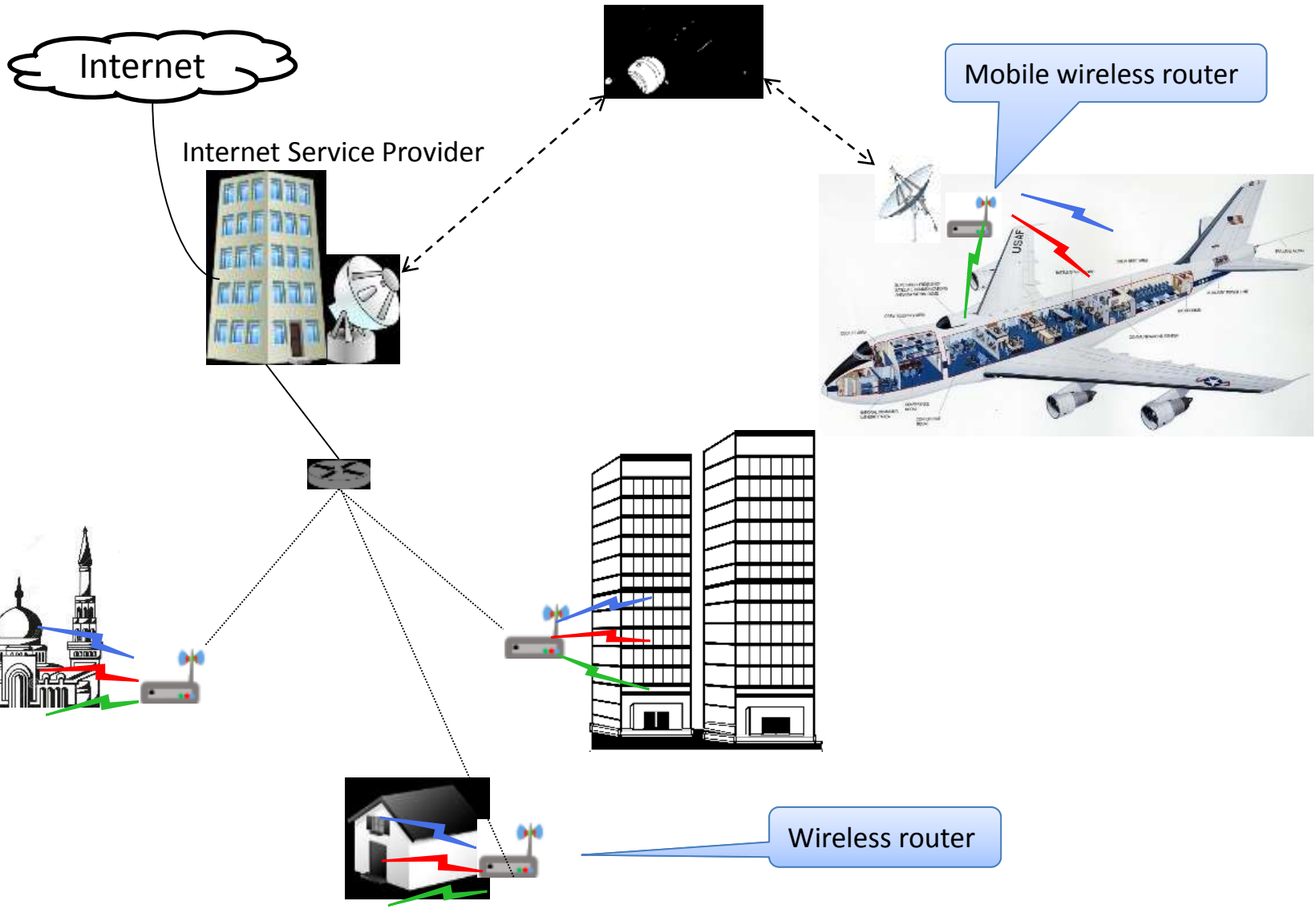
- Analysis of multi-band communication in Wi-Fi and LTE-A
- Increasing performance of Wi-Fi and LTE-A by developing resource allocation and scheduling methods

Scenario


Internet
Internet Service Provider
Mobile wireless router
Wireless router
LTE service towers
UE
UE
UE
LTE
RN
UE
UE

Multi-band Communication in Wi-Fi (802.11)

Scenario: 802.11



Wi-Fi (802.11) Over Generation[8]

97

2.4 GHz
1, 2 Mbps
DSSS,FHSS

a

5 GHz
54 Mbps
OFDM

2.4 GHz
11 Mbps
DSSS

b

g

2.4 GHz
54 Mbps
DSSS,OFDM

n

2.4, 5 GHz
65, 135 Mbps
OFDM

Multi-band

5 GHz
780 Mbps
OFDM

ac

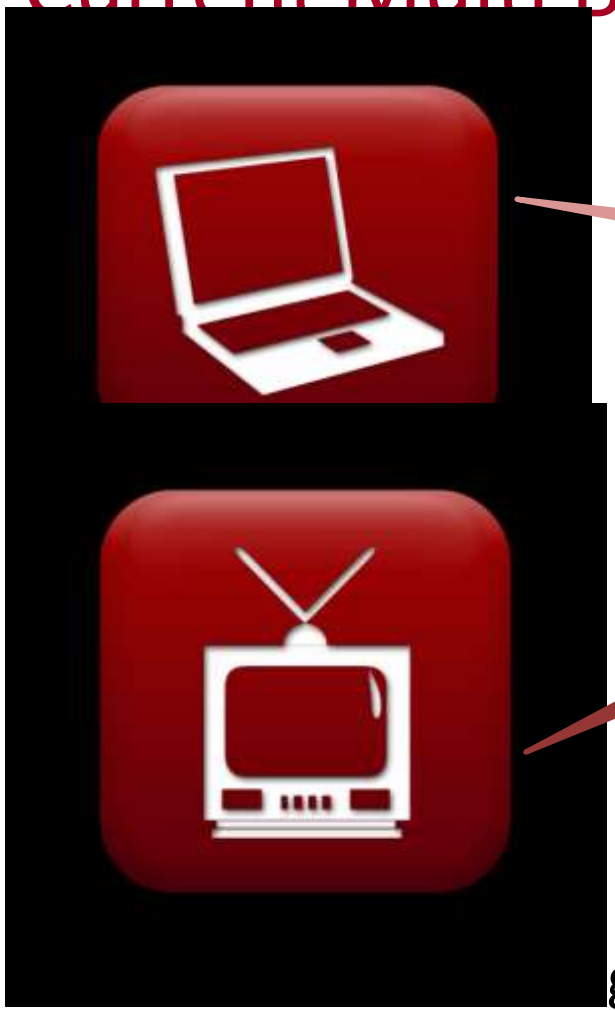
2.4, 5, 60 GHz
7 Gbps
OFDM

ad

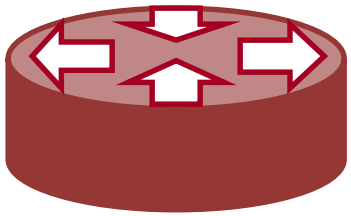
Future Ones

ah: 0.9 GHz
aj: 45, 60 GHz
ax: 2.4, 5 GHz

Current Multi Band (802.11n generation)[8]



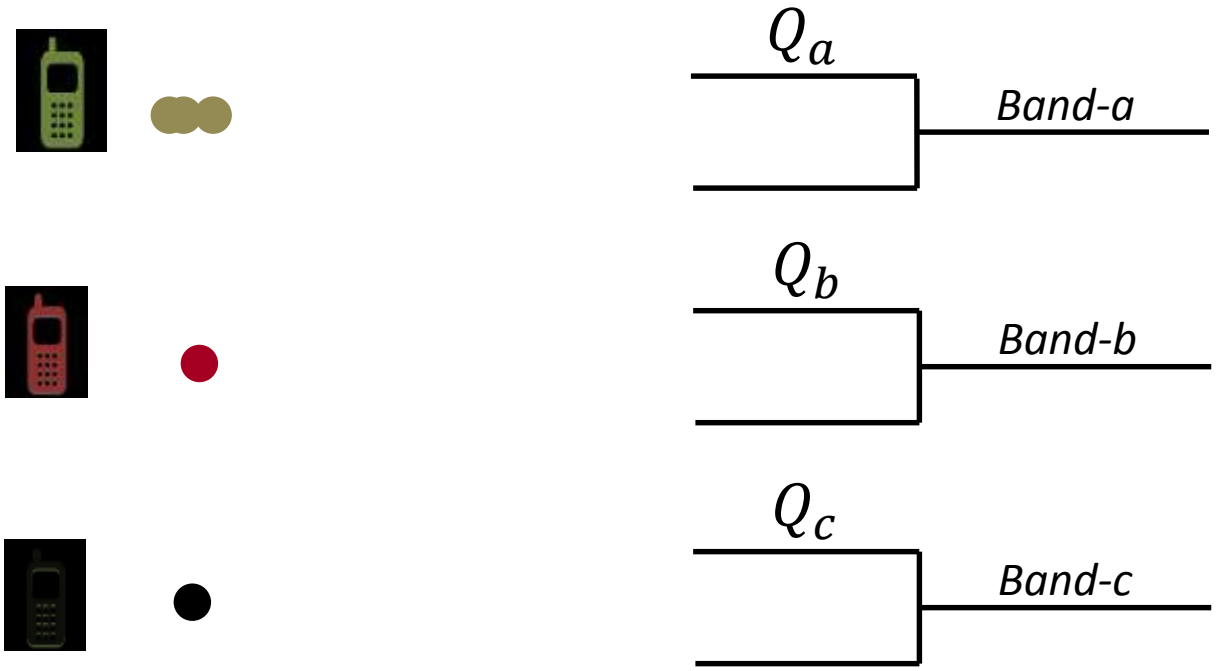
1st Band: 2.4 GHz



2nd Band: 5 GHz

g multi-band router is less interference, higher capacity and better reliability.

Current Multi-Band Queuing System[8]



Key Challenges (Resource Allocation)[8][10]

- Band utilization
- Traffic management
  - Real time
  - Non-real time
  - Binding update

First Problem Statement

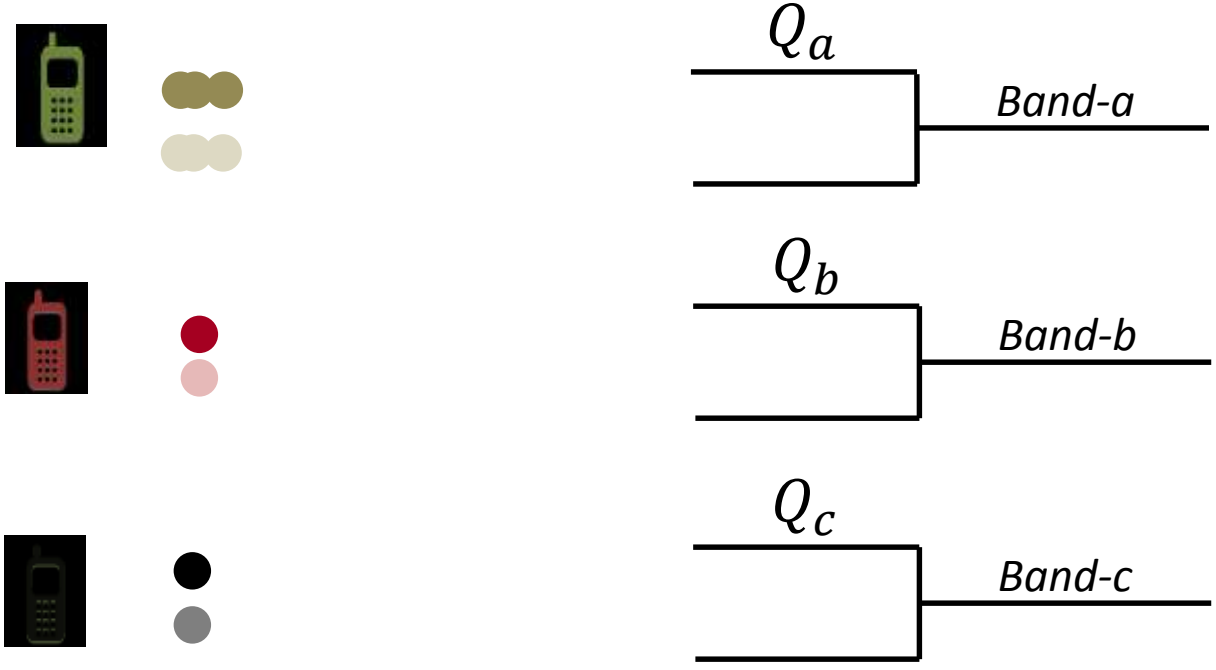
Utilizing bands of multi-band wireless routers and providing traffic management based on characteristic of bands

Current Solutions

- Traffic management methods based on priority[8][11*][12]
- Dynamic Channel Allocation methods[8][11*][13]
- Dynamic Bandwidth methods[8][11*]
  - Instead of using 20MHz, using 40MHz or more

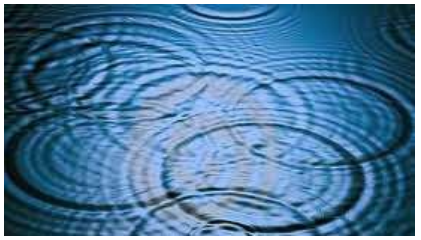
[8] http://grouper.ieee.org/groups/802/11/Reports/802.11_Timelines.htm
[11] http://www.cisco.com/c/en/us/td/docs/ios/12_2/qos/configuration/guide/fqos_c/qcfconmg.html

Current Multi-Band Priority Queuing System with Traffic Management

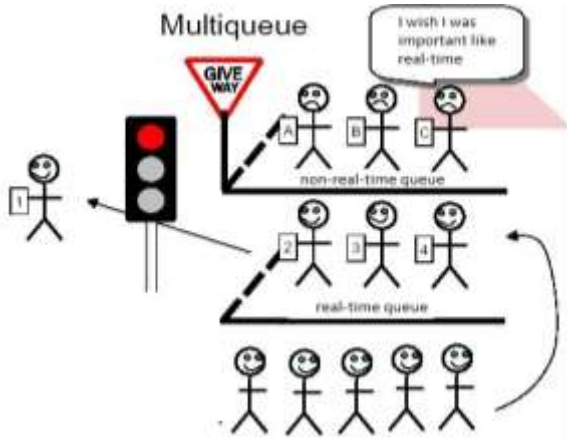


Disadvantages of Current Solutions

- Dynamic bandwidth
  - Instead of using 20MHz, using 40MHz or more
  - Increase interference
  - Advantage of bands are not considered
    - 2.4 GHz has higher range and 5 GHz has higher bandwidth



- Priority based traffic management methods.
  - Giving priority to real-time or non-real time traffics
    - One traffic can get all service
    - Threshold can be used for traffic service but finding optimum threshold is another problem



Disadvantages of Current Solutions

- Dynamic channel allocation
  - Good throughput
  - Traffic management
  - But not utilization
    - One band can serve but other cannot

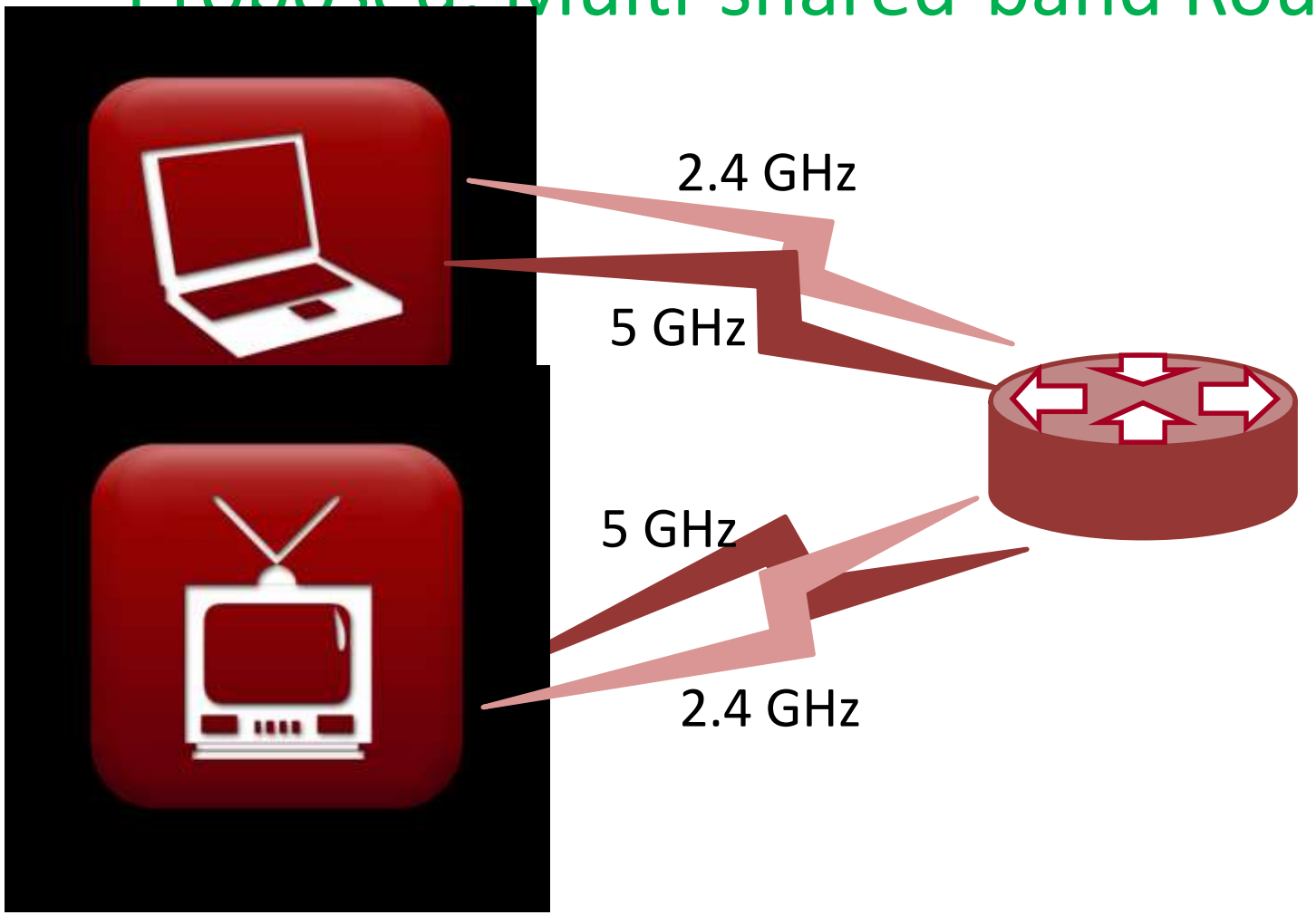
Why need another Router System

- Current multi-band routers do not utilize bands.
- No dynamic traffic management based on bands which also provide utilization.
  - Delay requirement of real time
  - Manual switching between bands
    - User may need to switch from one band to other.

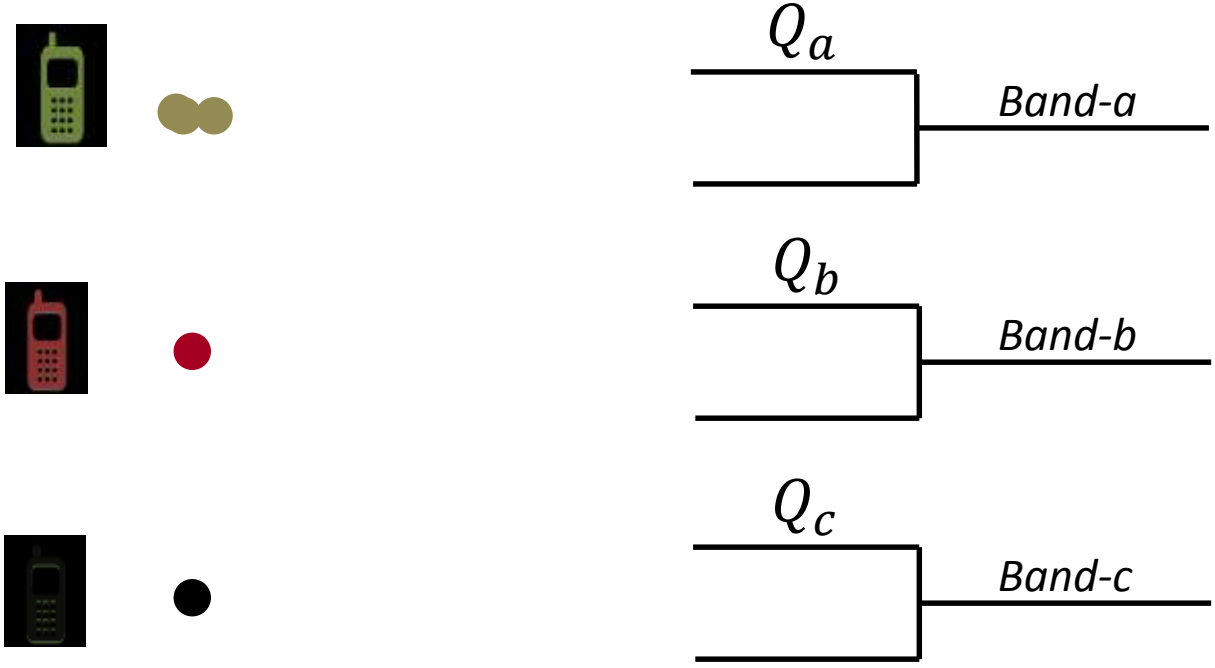
Reading and Idea

- IMT-Advanced and Future Communication System[13][14*]
- Each device may use multi-band simultaneously in 802.11
  - Smart home
    - High demand of bandwidth
    - 20 billion Internet connected device in 2020[43]
    - 1 pbps (petabit (10^{15}) per second in 50km) transfer over a fiber cable[46]

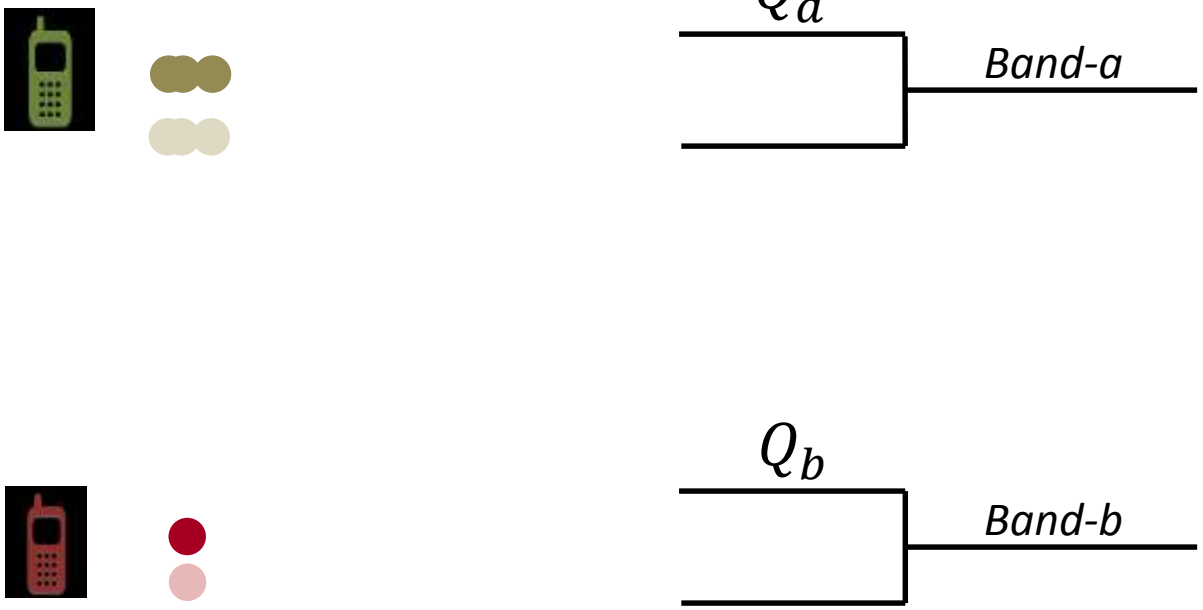
Proposed: Multi-shared-band Router



Multi-shared-band Queuing System



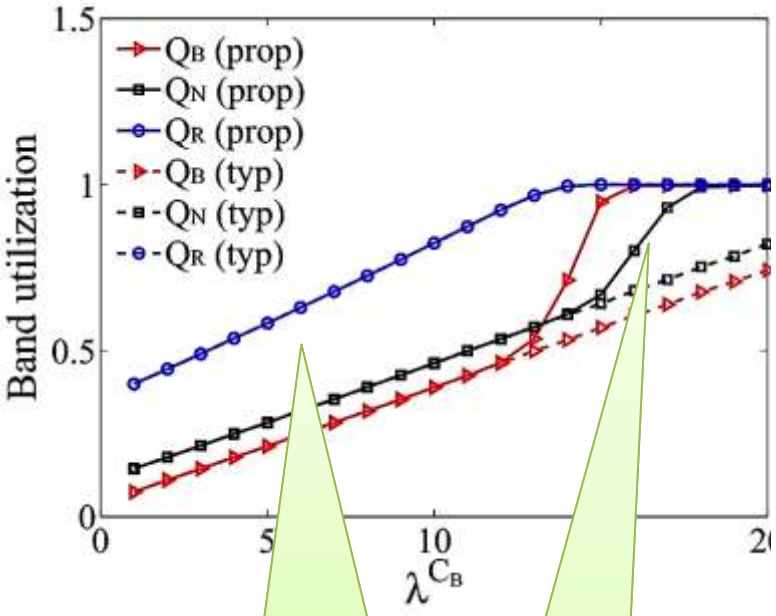
Multi-shared-band Queuing System with Traffic Types

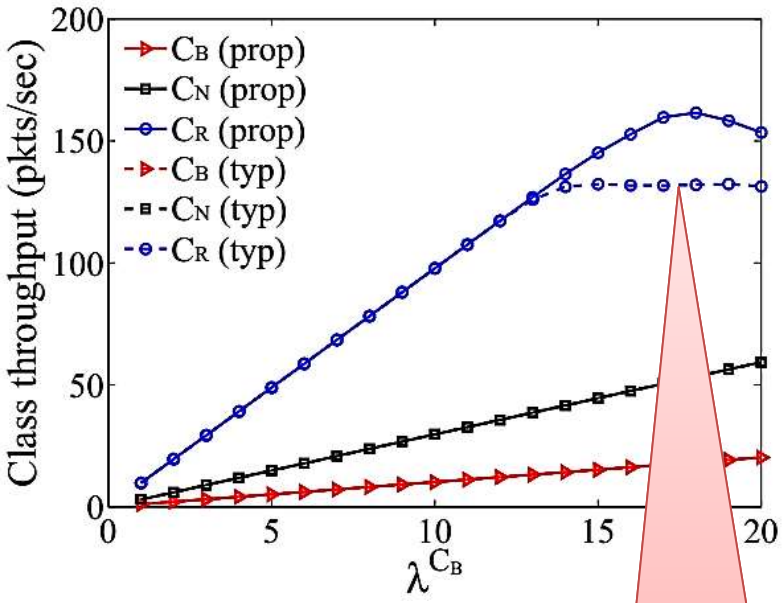


Scheduling and Analysis

- Scheduling by using FSF[19], SSF[19] and LUF
- Analysis of Performance based on Priority Queue Theory[16][17[18]
- Derived formulas are verified by implemented simulation

Result





Utilization is same for low loads

Utilization of proposed method is higher for high loads

Throughput of proposed method is higher for high loads

Improvements: Multi-shared-band Router

Improving throughput of multi-band by using multi-shared-band up to 23%.

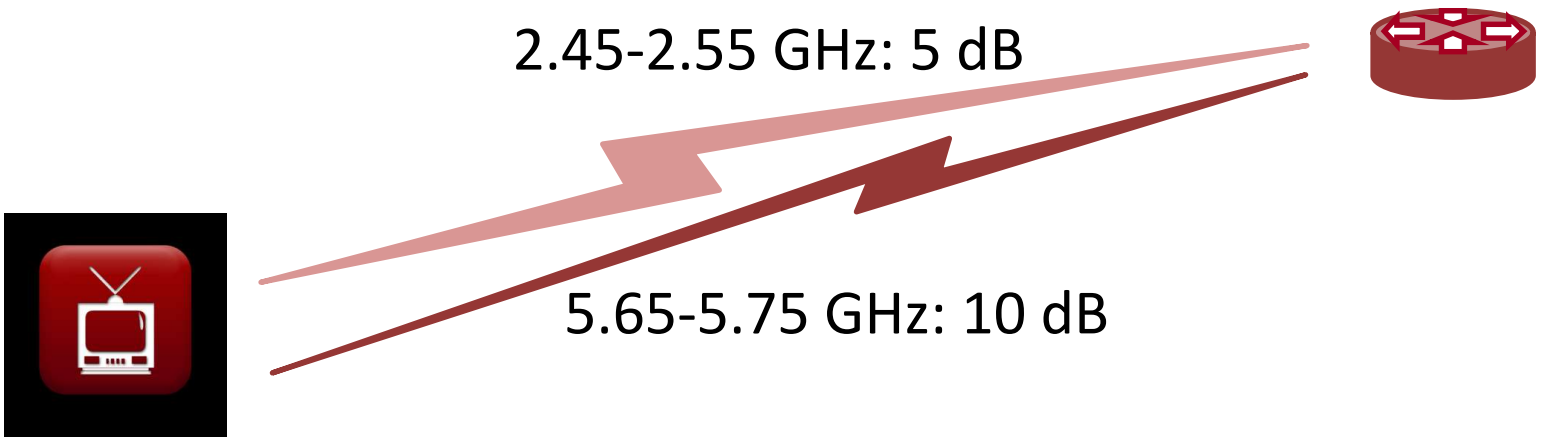
Multi-shared-band

Current Multi-band and Proposed Multi-shared-band Routers: Sub-problem

- Energy consumption is high[23][24]
  - $27 per year for a router even for stand by[23] (Ecotricity)

Current Solution for Sub-problem

- Channel selection based on power consumption by considering QoS[20].

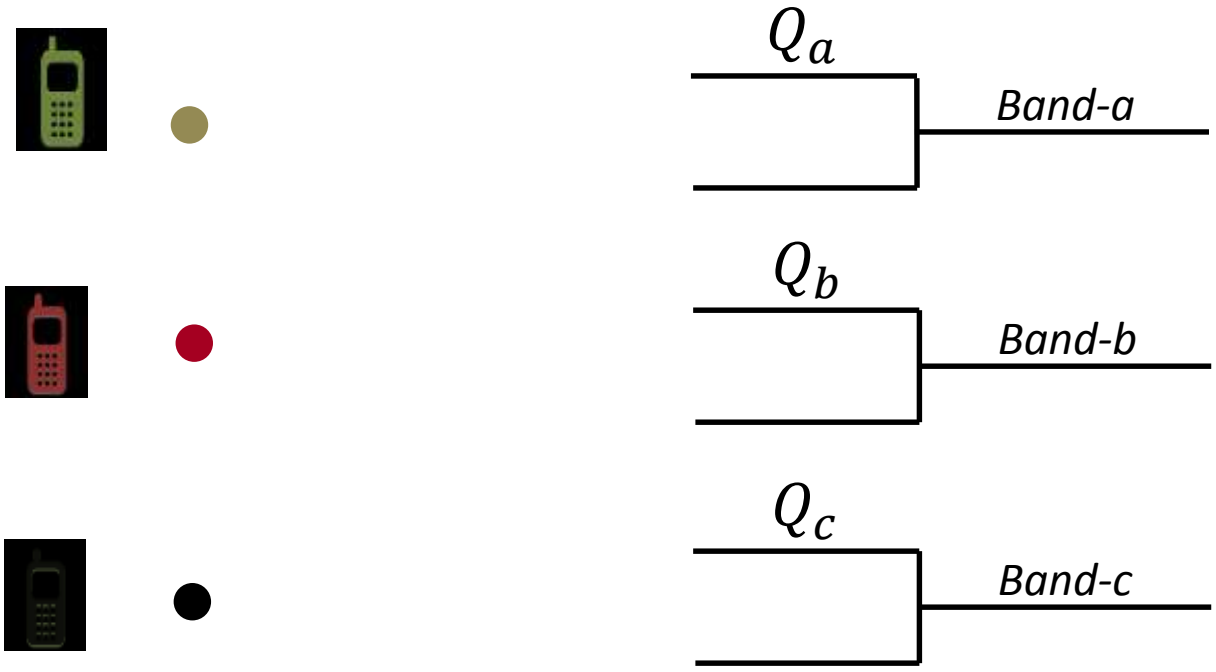


- Antenna Selection in MIMO[21]
  - Good for transferring data but not for stand by.
- Wake Sleep Procedure[22]
  - Small Amount of time in remote device (Not actual router)
- Using small packets[24]

Proposed: Energy Aware Scheduling Algorithm and Queue Management (e-ASA)

- Follows sleep and wake-up procedure of bands
- Depends on incoming traffic rates and QoS

e-ASA Based Multi-shared-band Scenario



Improvements: Multi-shared-band Router

Improving throughput of multi-band by using e-ASA based multi-shared-band up to 20%.

Multi-shared-band with e-ASA

Disadvantage of e-ASA: increasing delay

Up to 60% energy can be saved by using e-ASA.

e-ASA needs more investigation

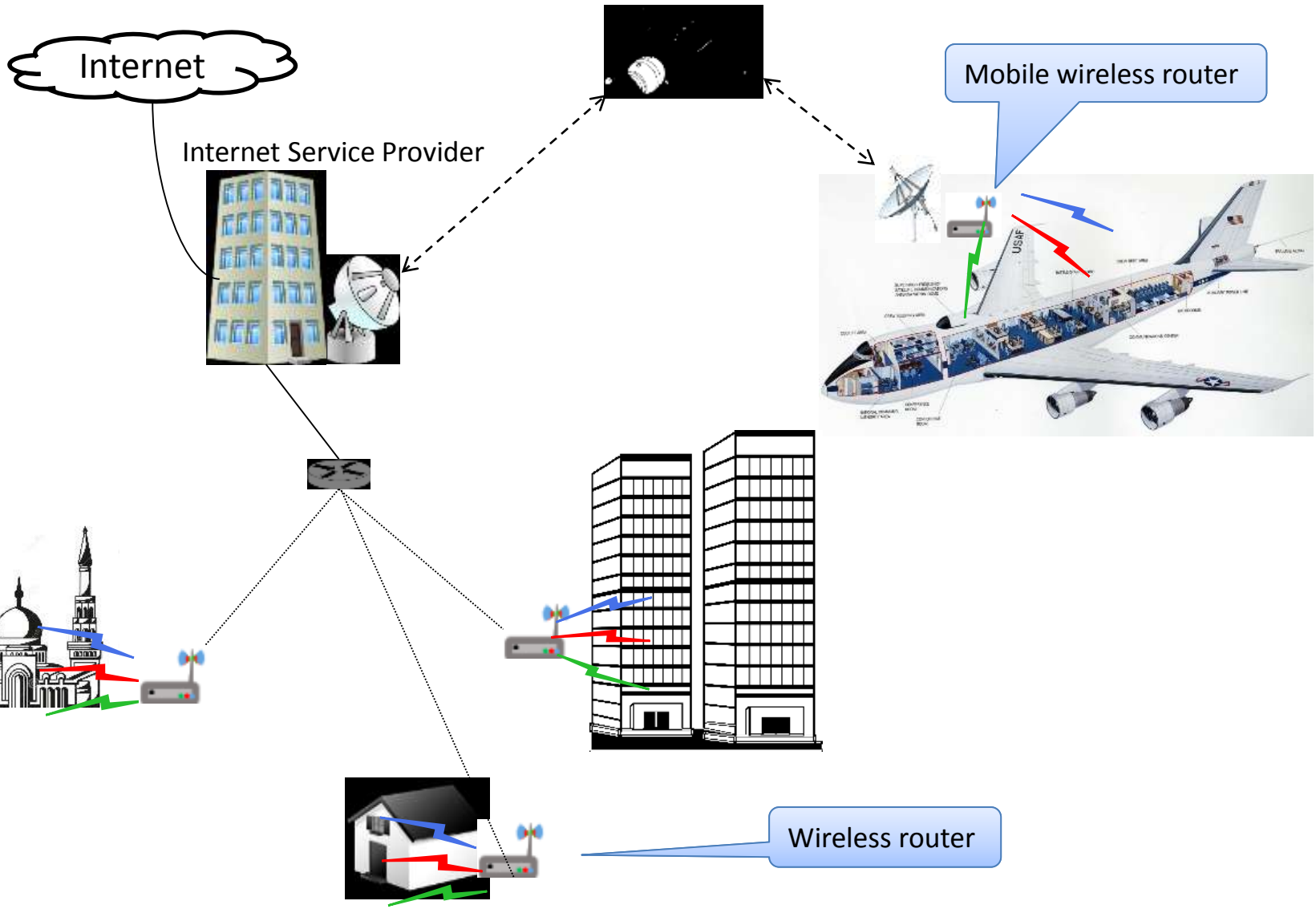
Contributions

- **Multi-class traffic scheduling and queue management** for multi-shared-band routers is proposed
- Developed **energy aware scheduling and queue management** for multi-band wireless router
- Evaluating performance of the proposed methods with queuing analysis methods and extensive simulations

Academic papers on multi-band in Wi-Fi

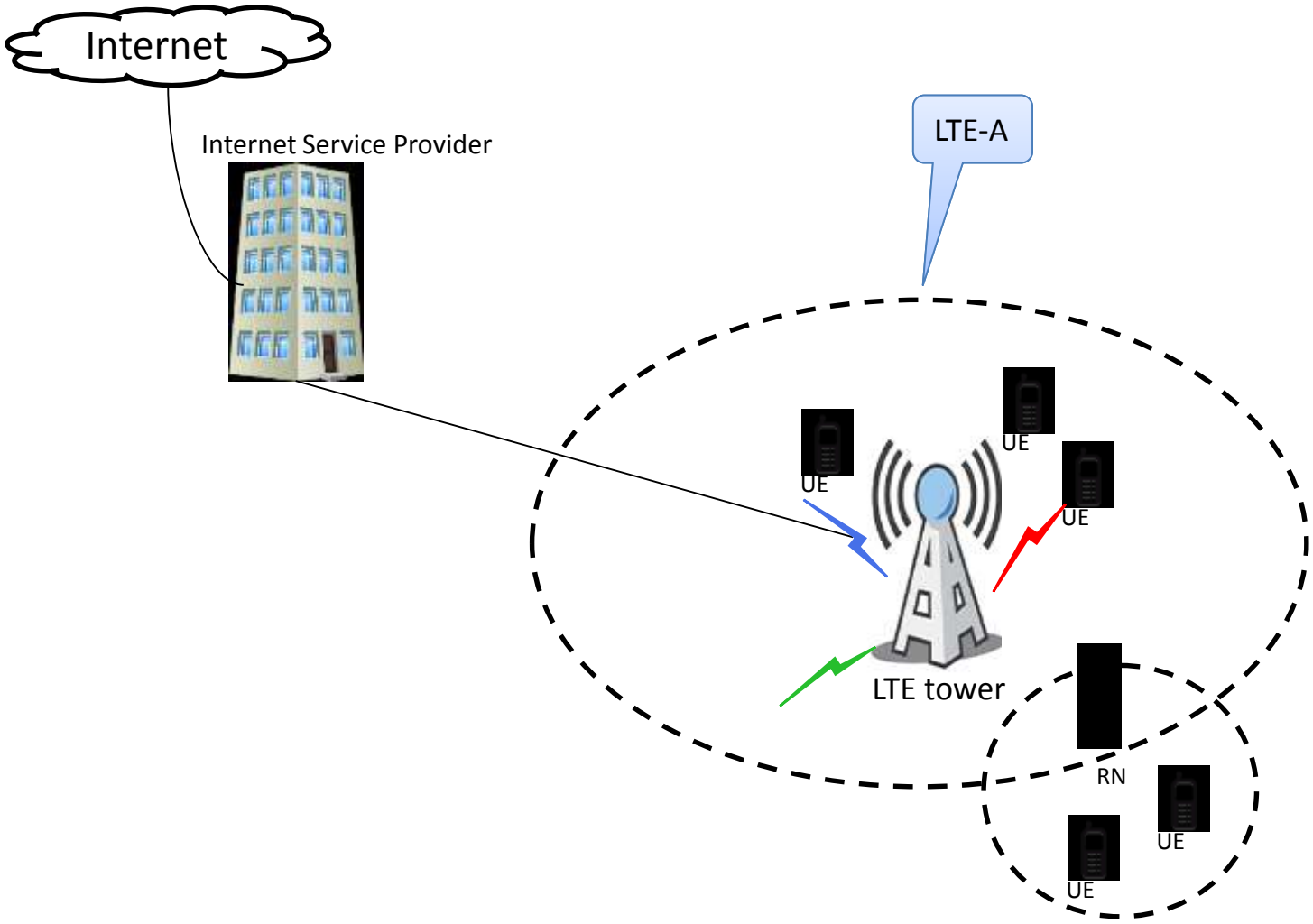
- [4] **Husnu S. Narman**, Md. Shohrab Hossain and Mohammed Atiquzzaman: *Management and Analysis of Multi Class Traffic in Single and Multi-Band Systems*, (Accepted, Springer WPC 2015)
- [3] **Husnu S. Narman** and Mohammed Atiquzzaman: *Energy Aware Scheduling and Queue Management for Next Generation Wi-Fi Routers*, (Accepted, IEEE WCNC 2015 workshop NGWiFi)
- [2] **Husnu S. Narman**, Md. Shohrab Hossain, and Mohammed Atiquzzaman: *Multi Class Traffic Analysis of Single and Multi-band Queuing System*, (IEEE GLOBECOM 2013 NGN)
- [1] Md. Shohrab Hossain, **Husnu S. Narman** and Mohammed Atiquzzaman: *A Novel Scheduling and Queue Management Scheme for Multi-band Mobile Routers*, (IEEE ICC 2013 NGN)

Scenario: 802.11

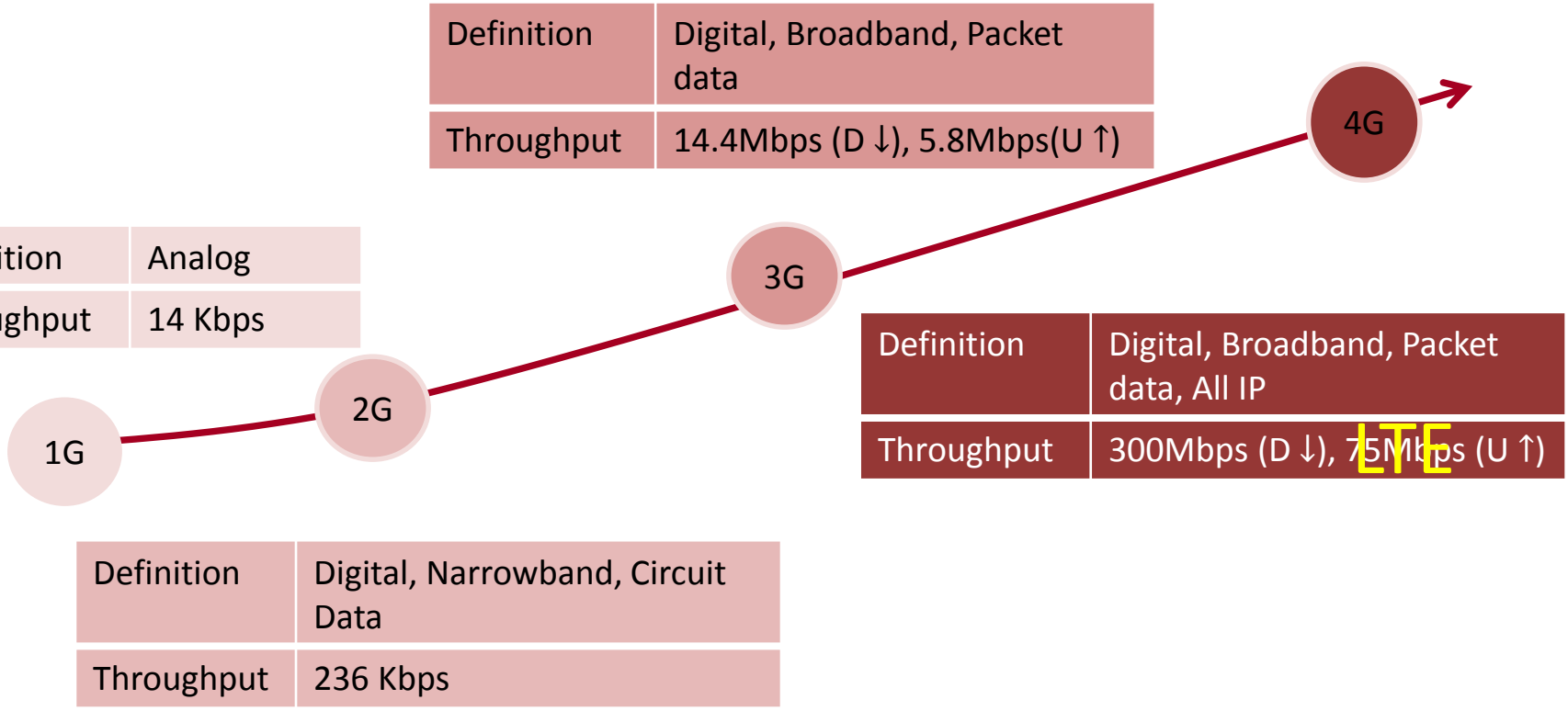


Multi-band Communication in LTE-A

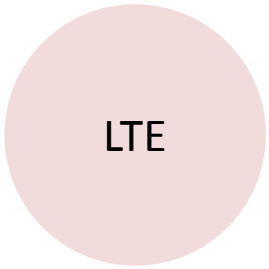
Scenario: LTE-A

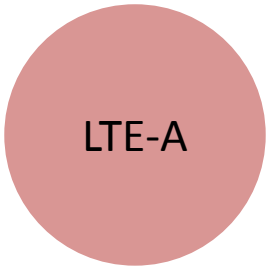


Communication Speed Over Generation[25][26]



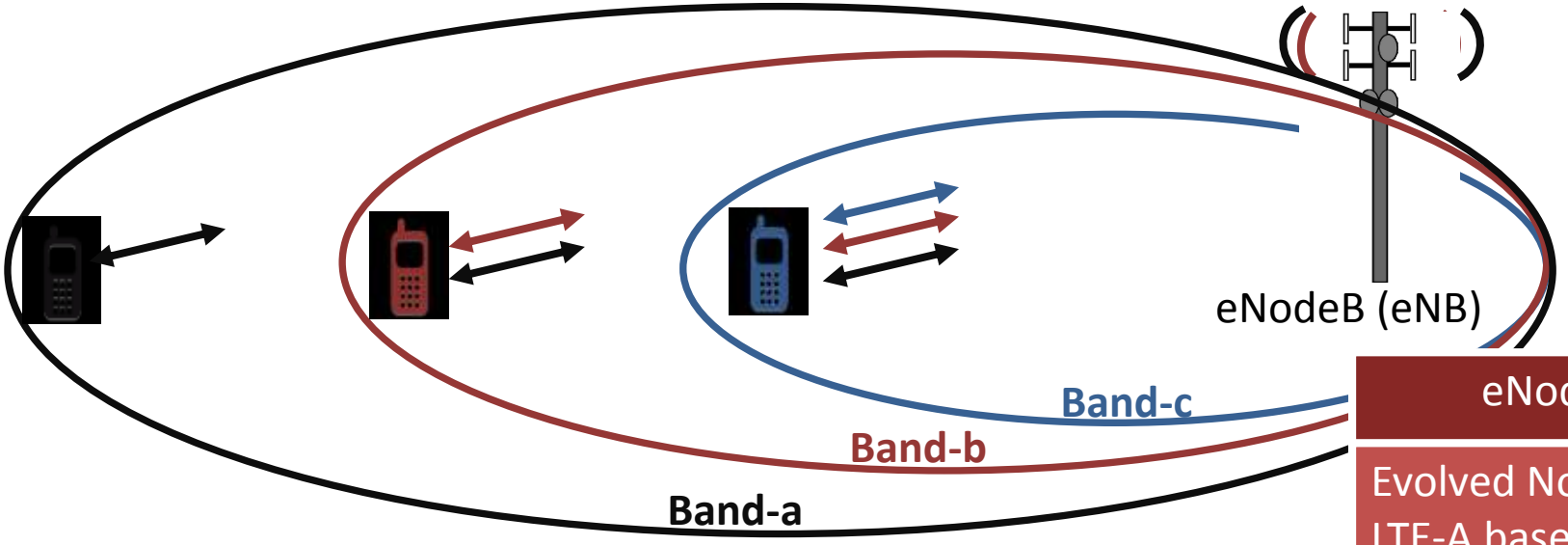
LTE and LTE-A





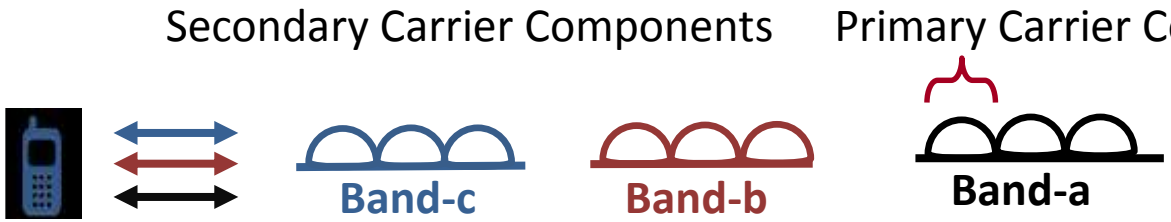
Theoretical Throughput	300Mbps (D ↓) - 75Mbps (U ↑)	3Gbps (D ↓) - 1.5Gbps (U ↑)
Experienced Throughput	13Mbps (D ↓) crowded area	
Technology	OFDMA (D ↓), SC-FDMA (U ↑)	OFDMA, CA, RN

Carrier Aggregation (CA)[27][28][45]



eNodeB

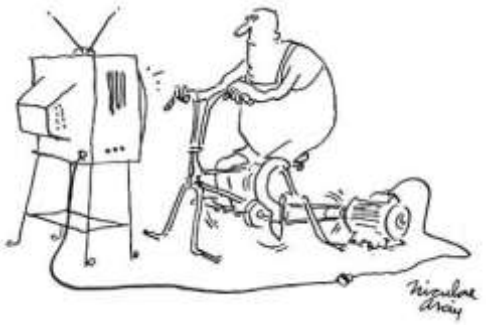
Evolved Node B:
LTE-A base station



Up to 5 Carrier Components (CC) for downlink and uplink

Key Challenges[27][28]

- Balancing user loads to bands
- Satisfying users
- Resource usage efficiency
  - Bandwidth
  - Power

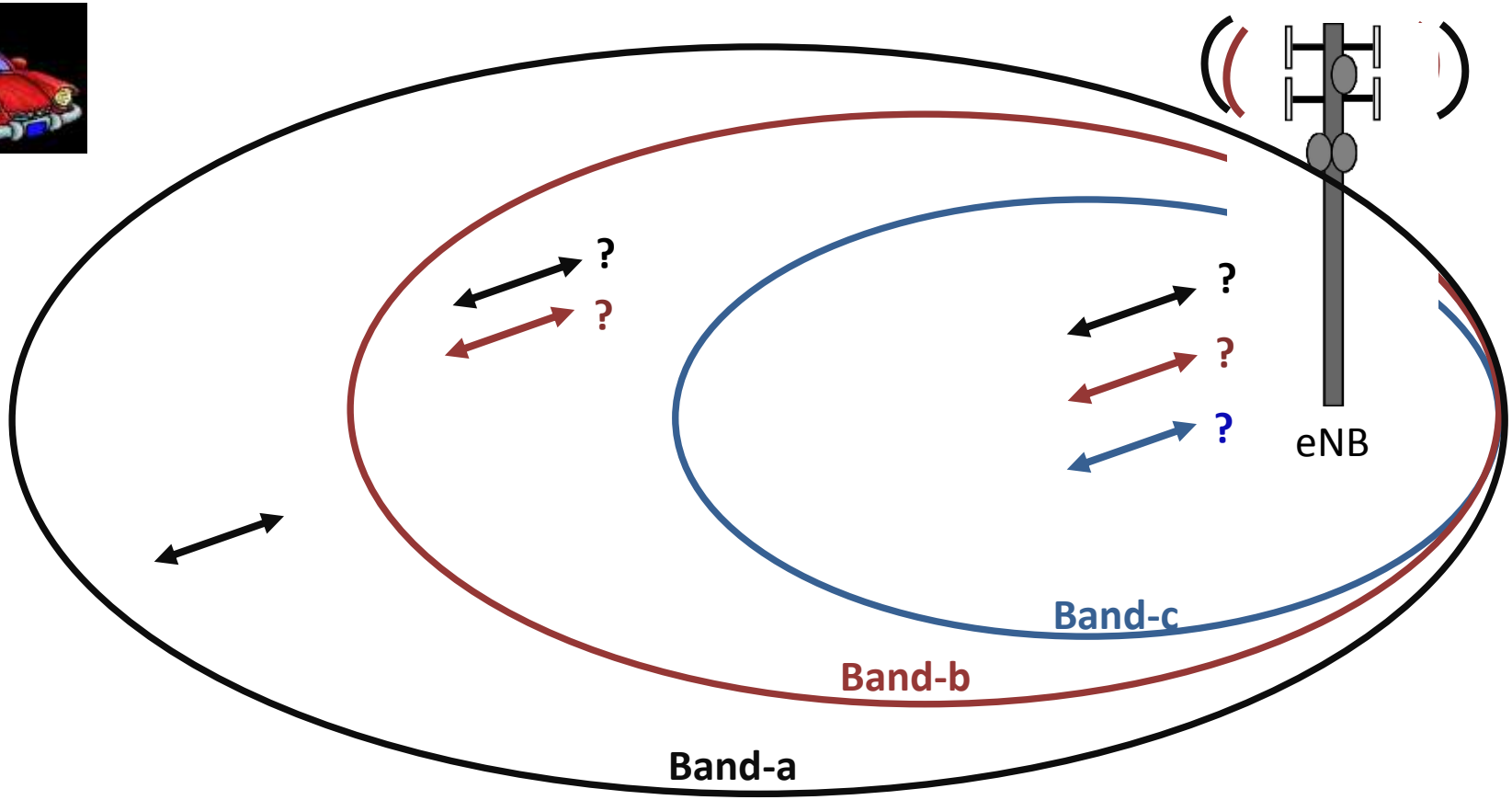


Second Problem Statement

Managing carrier assignment in LTE-A by considering users' demands without wasting resources (power and bands)

First Example

Which bands should eNB assign to each user?



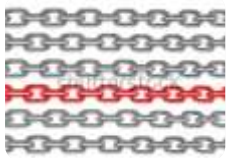
Second Example

How many CCs should be assigned to each user?

Current Solutions

- Carrier Assignments
  - Randomly select band for each user (R)[31][33]
    - Not utilize and balance bands in short term and no QoS[30]

  - Methods based on Load Balancing[32][34][35]
    - For example: Selecting Least Loaded band for each user (LL)



  - Methods based on Channel Quality Indicator (CQI) [36][37][38]
    - Assigning channel based on its quality
    - Providing QoS.

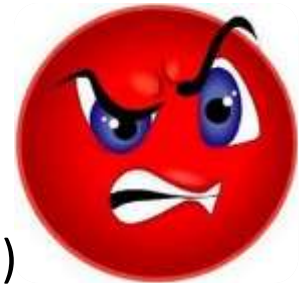
Current Solutions

- Number of Required CCs[28]
  - How many CCs is required?
    - All of CCs can be used[29] but increasing energy consumption of devices and interference[30]
    - Gradually increasing number of CCs but delay if more CCs needed

[29] Y. Wang, K. Pedersen, P. Mogensen, and T. Sorensen, "Carrier load balancing methods with bursty traffic for lte-advanced systems," in Personal, Indoor and Mobile Radio Communications, 2009 IEEE 20th International Symposium on, pp. 22 –26, sept. 2009
[31] H. Tian, S. Gao, J. Zhu, and L. Chen, "Improved component carrier selection method for non-continuous carrier aggregation in lte-advanced systems," in Vehicular Technology Conference (VTC Fall), 2011 IEEE, pp. 1 –5, sept. 2011
[32] L. Zhang, F. Liu, L. Huang, and W. Wang, "Traffic load balance methods in the lte-advanced system with carrier aggregation," in Communications, Circuits and Systems (ICCCAS), 2010 International Conference on, pp. 63 –67, july 2010.
[33] L. Lei and K. Zheng, "Performance evaluation of carrier aggregation for elastic traffic in lte-advanced systems," IEICE Transactions, pp. 3516–3519, 2009.
[34]] L. Zhang, K. Zheng, W. Wang, and L. Huang, "Performance analysis on carrier scheduling schemes in the long-term evolution-advanced system with carrier aggregation," Communications, IET, vol. 5, pp. 612 –619, 2011.
[35] Q. Europe, "LTE-A MC RF requirements for contiguous carriers," TR R4-091910, 3GPP TSG-RAN WG4 51, Apr. 2009
[36] H. Wang, C. Rosa, and K. I. Pedersen, "Performance analysis of downlink inter-band carrier aggregation in lte-advanced.," in VTC Fall, pp. 1–5, IEEE, 2011
[37] L. Liu, M. Li, J. Zhou, X. She, L. Chen, Y. Sagae, and M. Iwamura, "Component carrier management for carrier aggregation in lte-advanced system," in Vehicular Technology Conference (VTC Spring), 2011 IEEE 73rd, pp. 1 –6, May 2011.
[38] A. Mihovska, "Spectrum aggregation with optimal multi-band scheduling," Wireless Personal Multimedia Communications Symposia. Proceedings, vol. 2010, pp. S11–4, 2010.

Why need another Carrier Assignment Method?

- More advance Carrier Assignment Method is required to satisfy users[40]
  - Increasing bandwidth demand
    - 2 billion smart phones and tablets in 2017[44]
  - Limitation of resources (battery of devices and bandwidth)
  - Traffic management (real time and non-real time traffic)



- Measuring the number of required Carrier Components

User Profile Examples[40][42]

			User Profile				
			Teenager	**House wife**	**Businessman**	**Graduate Student**	**Grand Parent**
Traffic Types	**RT**	**Video**	Very High	Middle	Low	Medium	Low
		Online game	Very High	Low	Low	Medium	Low
		Movie	Very High	Very High	Low	Medium	Low
		Talk	Low	Medium	High	Medium	Very High
	NRT	**Web**	High	Low	Very High	Medium	Low
		Mail	High	Low	Very High	Medium	Low
		SMS	Very High	Medium	Low	Medium	Low
		Mobility[41]	Low	Medium	Very High	Low	Low
		Location	Low	Medium	High	Medium	Low

Why: Carrier Assignment Based on User Profile

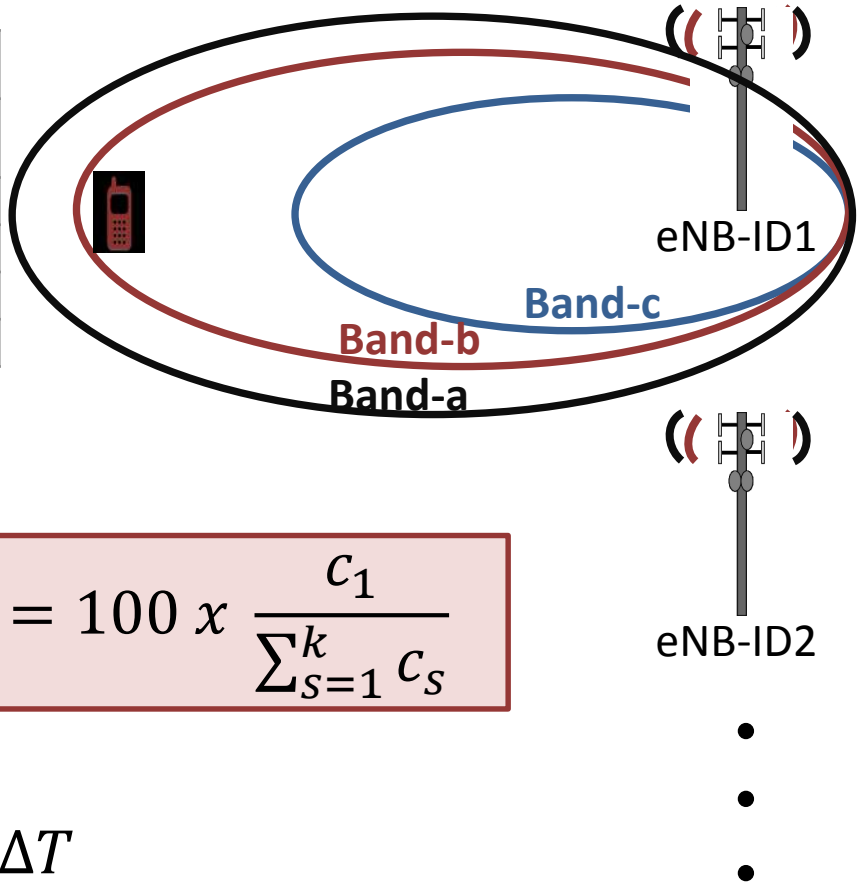
- User profile of each user for each eNB
  - Application type
    - What type of applications are used by users? (such as game, mail, video, talking..)
  - Data consumption
    - How much data do users use? (such as 100MB non-real time, 1GB real time)
  - Time
    - When do users mostly consume data during the day? (such as 10:00 am – 11:00 am)
  - Location
    - Where do users spend the most time during the day? (such as school, work, road …)
  - Users' device type
    - LTE (Only 1 CC), LTE-A full (Up to 5 CCs), LTE-A low (Only 1 CC)

Proposed: Carrier Assignment Based on User Profile

- Depends on
  - Type of device used
  - User behaviors
  - Balance techniques
  - CQI
- Benefits of User Profile
  - Satisfying users based on their behaviors

User Profile Detection

	Band-a/Band-b/Band-c			RT Services		NRT Services	
eNB-ID	Times	Connection Time	Idle Time	Video	Game	Web	Mail
ID1	f1	c1	t1	v1	g1	w1	m1
ID2	f2	c2	t2	v2	g2	w2	m2
ID3	f3	c3	t3	v3	g3	w3	m3
ID4	f4	c4	t4	v4	g4	w4	m4



Statistical examples:

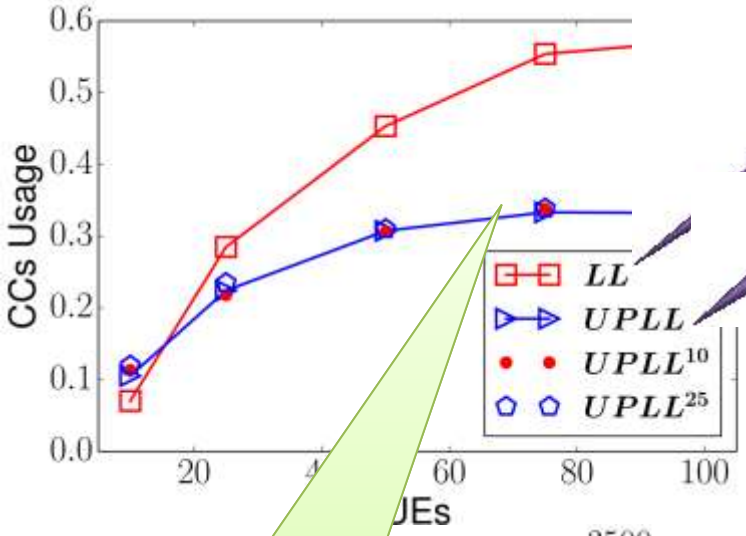
$$\Delta T_j^i = 100\ x\ \frac{f_1}{\sum_{s=1}^{k} f_s}$$

$$\Delta C_j^i = 100\ x\ \frac{c_1}{\sum_{s=1}^{k} c_s}$$

Examples

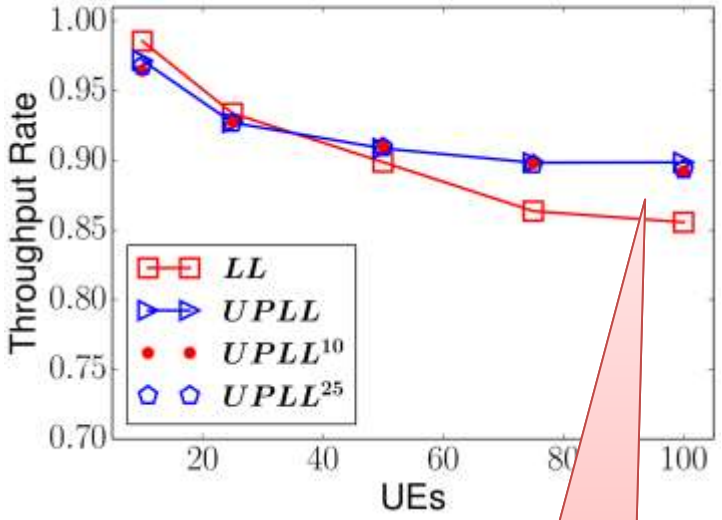
- Case1: Higher ΔC and lower ΔT
- Case2: Lower ΔC and higher ΔT

Result

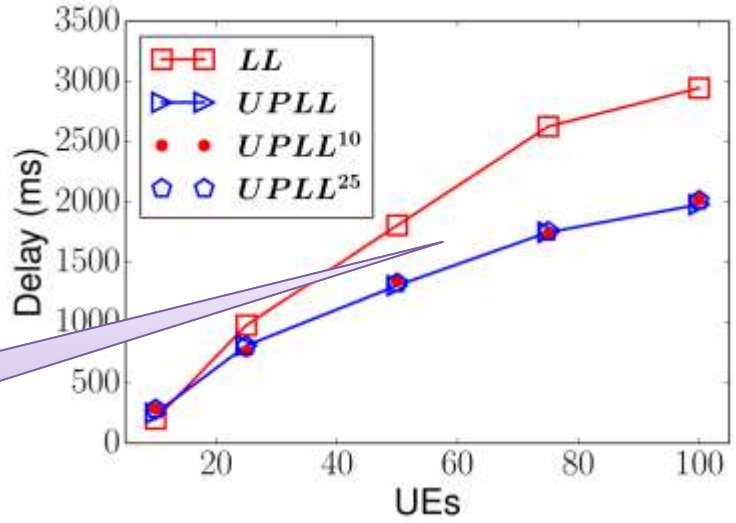


LL and CQI

UP, LL and CQI



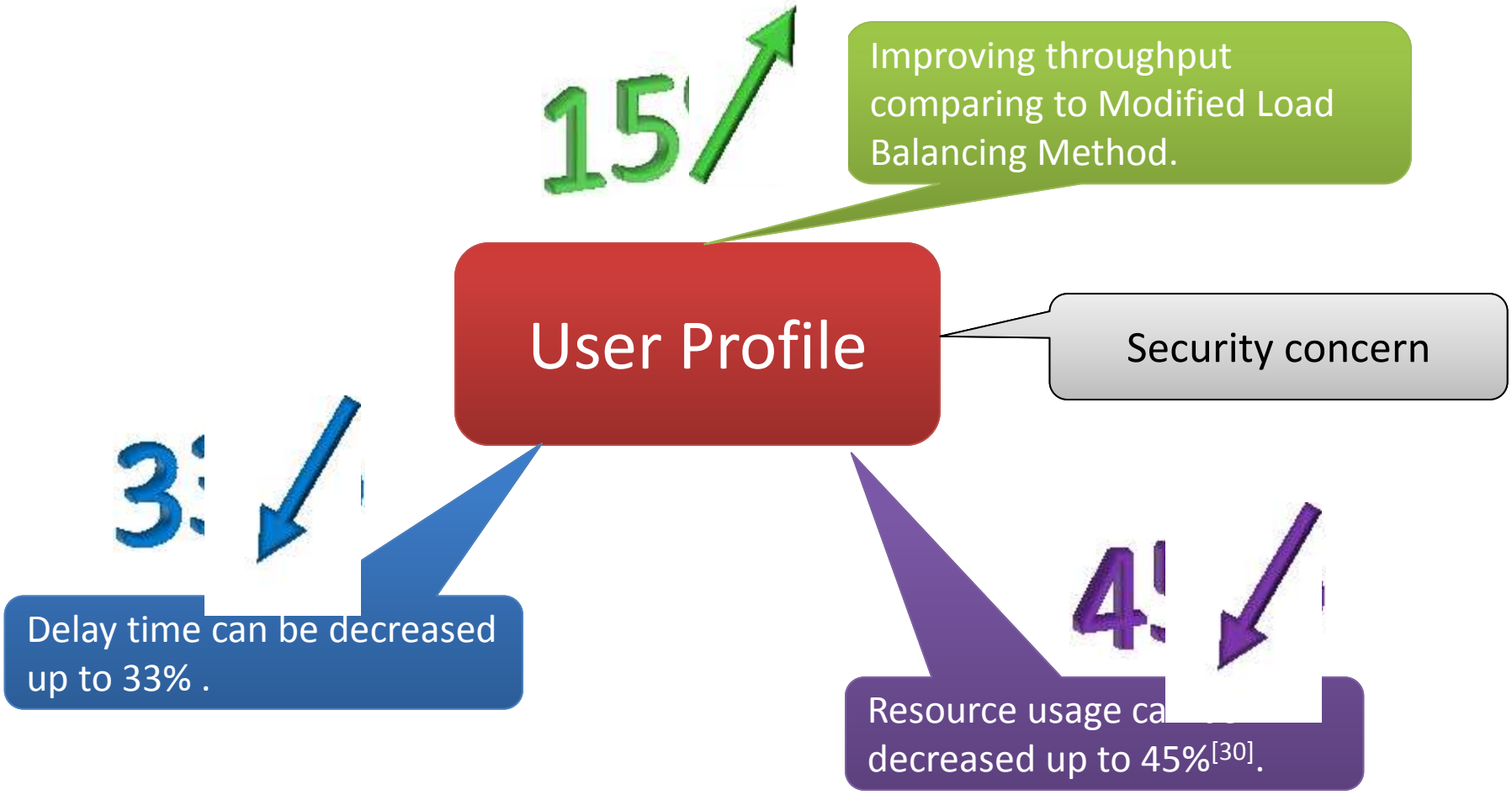
CCs usage of propose method is very good.



Delay of proposed method is lower.

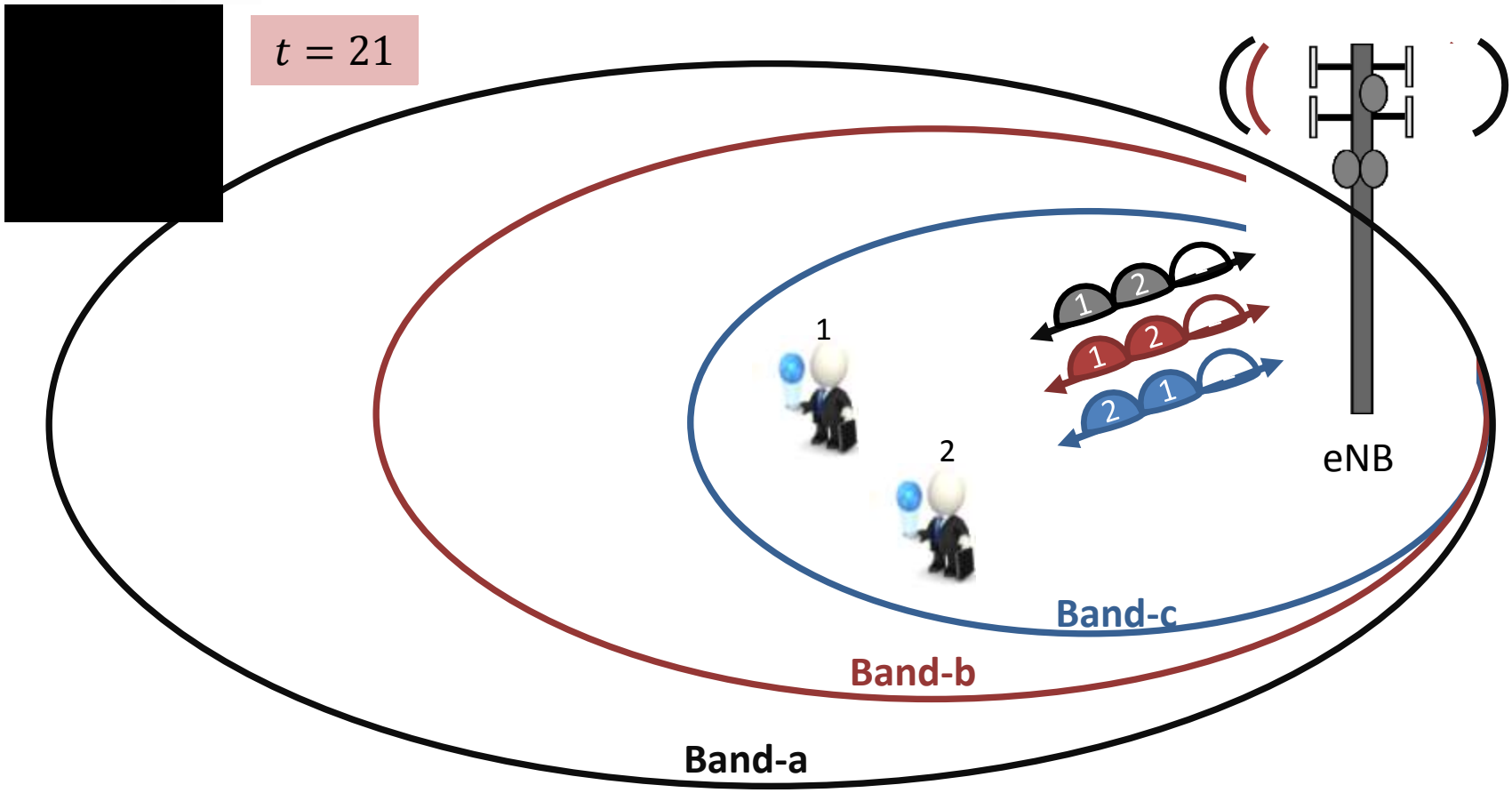
Throughput of proposed method is higher for high loads

Improvements: User Profile

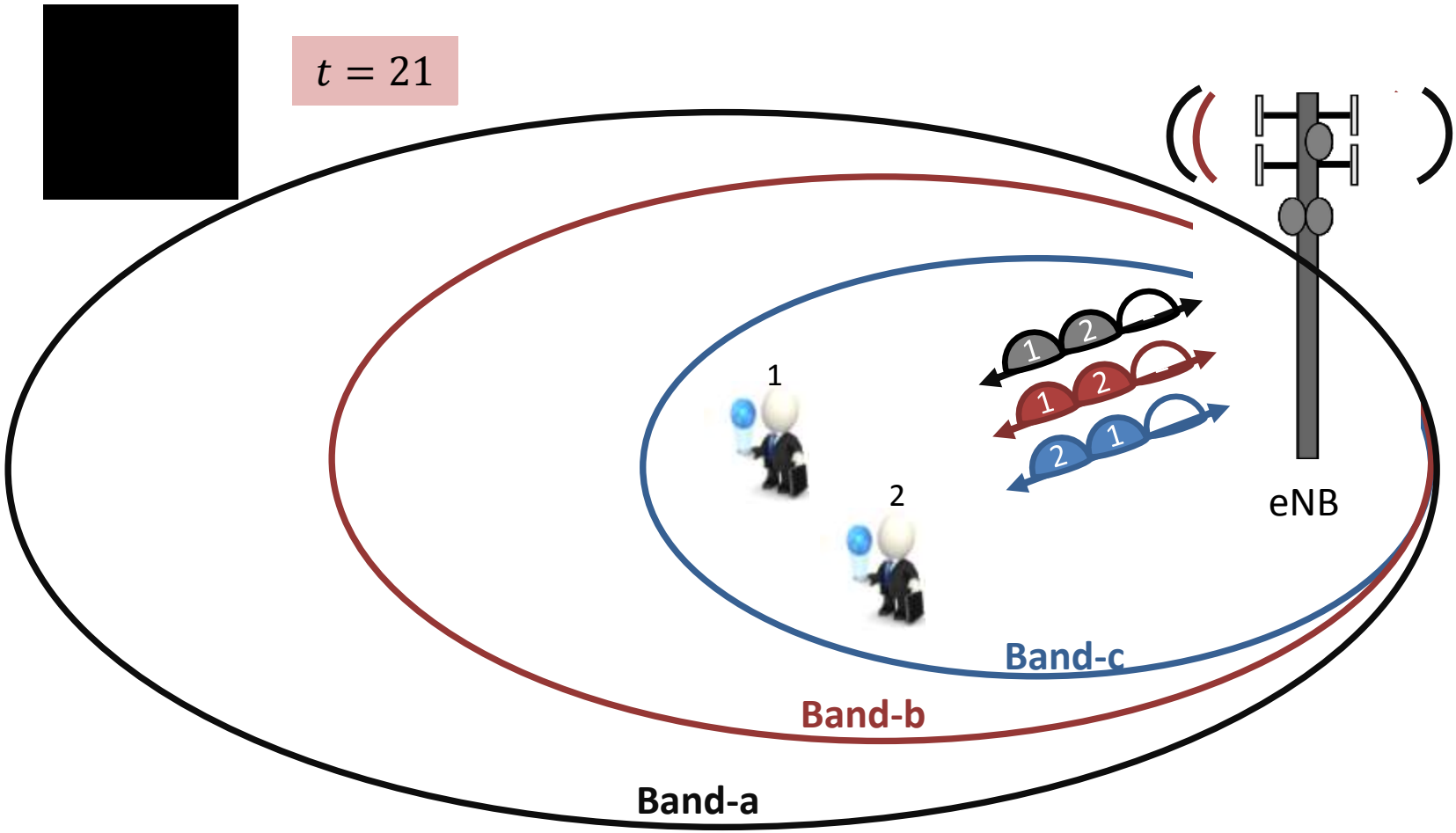


Sub-problem[39]

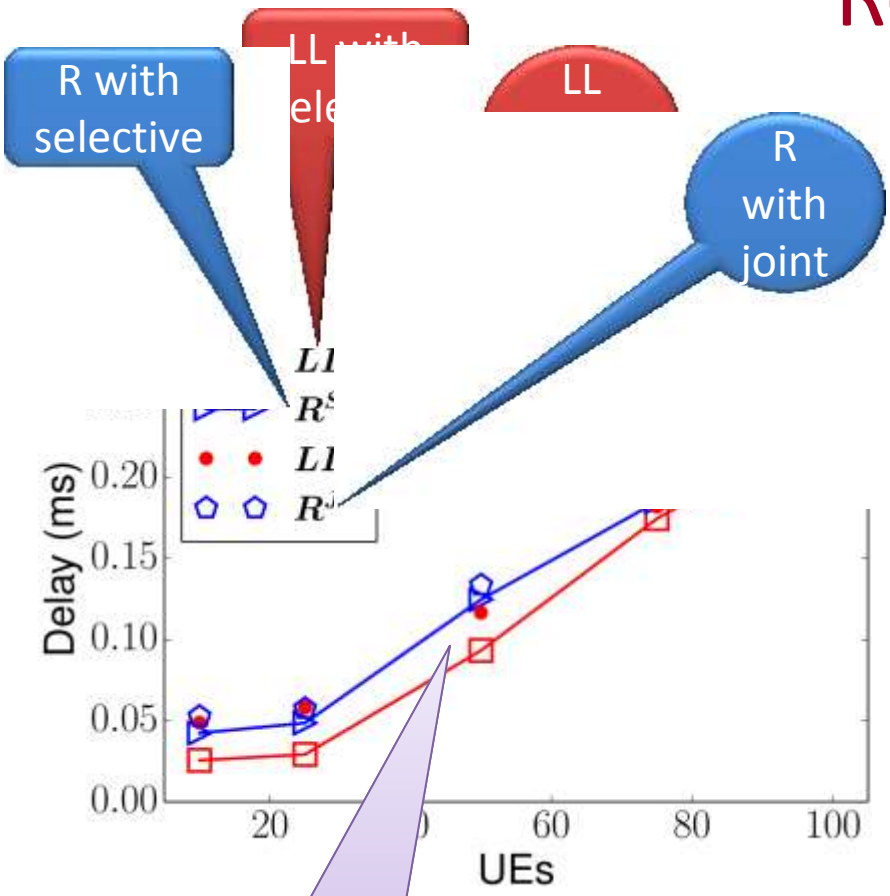
Periodic reassignment of carrier components jointly happened for all users?



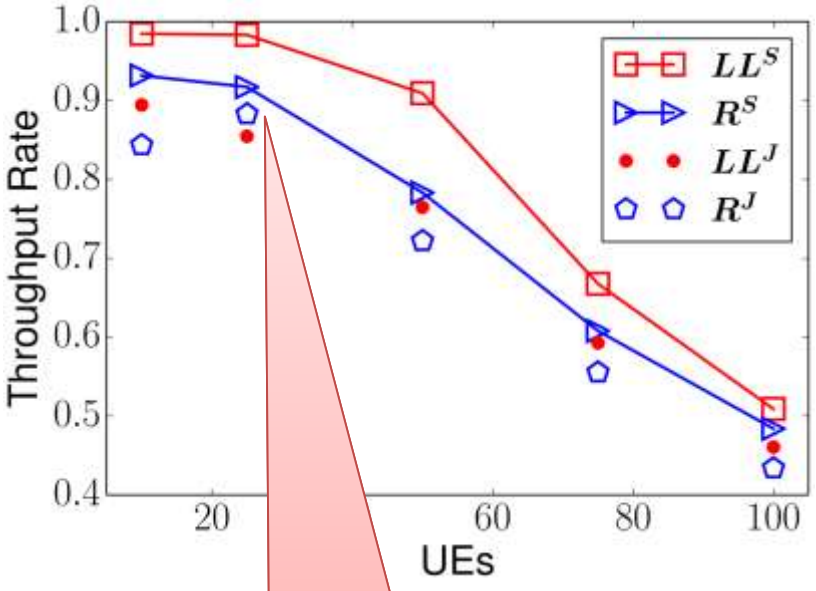
Selective CCs for Periodic Assignment for sub-problem



Result



Delay of proposed method is lower.



Throughput of proposed method is higher.

Improvements: Selective CCs for Periodic Assignment

Improving throughput up to 20% comparing to joint periodic CCs assignment.

Selective-Periodic

Decreasing delay time up to 25% comparing to joint periodic CCs assignment.

Contributions

- Proposing a **novel carrier assignment method based on user profile** for carrier aggregation
- **Selective CCs techniques is developed** for periodic CCs assignment
- Evaluating performance of the proposed methods with queuing analysis methods and extensive simulations

Academic papers on multi-band in LTE-A

- [7] **Husnu S. Narman** and Mohammed Atiquzzaman: *Analysis of Joint and Partial Carrier Components Assignment Techniques in LTE-A,* (Submitted, IEEE ICC 2015 workshop IWSDN)
- [6] **Husnu S. Narman** and Mohammed Atiquzzaman: *Joint and Partial Carrier Components Assignment Techniques Based on User Profile in LTE Systems*, (Accepted, IEEE WCNC 2015 Mac and Cross Layer Design)
- [5] **Husnu S. Narman** and Mohammed Atiquzzaman: *Carrier Components Assignment Method for LTE and LTE-A Systems Based on User Profile and Application*, (IEEE GLOBECOM 2014 workshop BWA)

Conclusion

Multi-band communication in Wi-Fi has been analyzed.

A scheduling and queue management algorithm has been proposed for Wi-Fi to increase throughput and energy efficiency.

Carrier assignment techniques of multi-band has been analyzed in LTE-A.

A carrier assignment method based on User Profile and selective periodic technique is proposed to improve LTE-A system performance.

Extra academic papers on Cloud Computing

- [10] **Husnu S. Narman**, Md. Shohrab Hossain and Mohammed Atiquzzaman: *Scheduling Internet of Things Applications in Cloud Computing*, (Submitted, Elsevier Future Generation Computer Systems 2014)

- [9] **Husnu S. Narman**, Md. Shohrab Hossain, and Mohammed Atiquzzaman: *h-DDSS: Heterogeneous Dynamic Dedicated Servers Scheduling in Cloud Computing*, (IEEE ICC 2014 SAC)

- [8] **Husnu S. Narman**, Md. Shohrab Hossain, and Mohammed Atiquzzaman: *DDSS: Dynamic Dedicated Servers Scheduling for Multi Priority Level Classes in Cloud Computing*, (IEEE ICC 2014 NGN)

Thank You

http://students.ou.edu/N/Husnu.S.Narman-1
husnu@ou.edu

References

[1] Vijay Garg, “Wireless Communications & Networking”, Elseveir, Morgan Kaufmann, June 2007
[2] Kiourti, K. A. Psathas, J. R. Costa, C. A. Fernandes, and K. S. Nikita, "Dual-band implantable antennas for medical telemetry: a fast design methodology and validation for intra-cranial pressure monitoring," *Progress In Electromagnetics Research*, Vol. 141, 161-183, 2013
[3] Ozbay, Cahit; Teter, W.; He, Donya; Sherman, M.J.; Schneider, G.L.; Benjamin, J.A., "Design and Implementation Challenges in Ka/Ku Dual-Band SATCOM-On-The-Move Terminals for Military Applications," *Military Communications Conference, 2006. MILCOM 2006. IEEE* , vol., no., pp.1,7, 23-25 Oct. 2006
[4] Ying Chen, Pedro Henrique Gomes, Bhaskar Krishnamachari, “Multi-Channel Data Collection for Throughput Maximization in Wireless Sensor Networks“, IEEE International Conference on Mobile Ad hoc and Sensor Systems (MASS), 2014
[5] Yaacoub, E.; Dawy, Z., "A Survey on Uplink Resource Allocation in OFDMA Wireless Networks, " *Communications Surveys & Tutorials, IEEE* , vol.14, no.2, pp.322,337, Second Quarter 2012
[6] Zhu Ji; Liu, K.J.R., "COGNITIVE RADIOS FOR DYNAMIC SPECTRUM ACCESS - Dynamic Spectrum Sharing: A Game Theoretical Overview," *Communications Magazine, IEEE* , vol.45, no.5, pp.88,94, May 2007
[7] Ian F. Akyildiz, David M. Gutierrez-Estevez, and Elias Chavarria Reyes. 2010. The evolution to 4G cellular systems: LTE-Advanced. *Phys. Commun.* 3, 4 (December 2010), 217-244.
[8] http://grouper.ieee.org/groups/802/11/Reports/802.11_Timelines.htm
[9] Jihua Tian; Jinping Sun; Guohua Wang; Yanping Wang; Weixian Tan, "Multiband Radar Signal Coherent Fusion Processing With IAA and apFFT," *Signal Processing Letters, IEEE* , vol.20, no.5, pp.463,466, May 2013
[10] Parikh, P.P.; Kanabar, M.G.; Sidhu, T.S., "Opportunities and challenges of wireless communication technologies for smart grid applications," *Power and Energy Society General Meeting, 2010 IEEE* , vol., no., pp.1,7, 25-29 July 2010

References (Cont.)

[11] http://www.cisco.com/c/en/us/td/docs/ios/12_2/qos/configuration/guide/fqos_c/qcfconmg.html
[12] Deepankar Medhi, Network Routing: Algorithms, Protocols, and Architectures. Morgan Kaufmann, April 12, 2007
[13] Dawei Gong, Miao Zhao, and Yuanyuan Yang. 2014. Distributed channel assignment algorithms for 802.11n WLANs with heterogeneous clients. *J. Parallel Distrib. Comput.* 74, 5 (May 2014), 2365-2379
[14] L. Verma and S. S. Lee, "Multi-band Wi-Fi systems: A new direction in personal and community connectivity," in IEEE International Conference on Consumer Electronics (ICCE), Las Vegas, NV, Jan 9-12, 2011, pp. 665–666.
[15] Doppler, K.; Wijting, C.; Henttonen, T. & Valkealahti, K. (2008), 'Multiband Scheduler for Future Communication Systems.',*IJCNS* **1** (1) , 1-9
[16] D. Gross, J. Shortle, J. Thompson, and C. M. Harris, Fundamentals of Queueing Theory. Wiley-Interscience, Aug 2008.
[17] K. E. Avrachenkov, N. O. Vilchevsky, and G. L. Shevlyakov, "Priority queueing with finite buffer size and randomized push-out mechanism," Performance Evaluation, vol. 61, Oct 2005.
[18] V. Zaborovsky, O. Zayats, and V. Mulukha, "Priority queueing with finite buffer size and randomized push-out mechanism," in International Conference on Networking, Menuires, Apr 11-16, 2010, pp. 316–320.
[19] F. S. Q. Alves, H. C. Yehia, L. A. C. Pedrosa, F. R. B. Cruz, and L. Kerbache, "Upper bounds on performance measures of heterogeneous M/M/c queues," Mathematical Problems in Engineering, vol. 2011, May 2011.
[20] Siriwongpairat, W.P.; Zhu Han; Liu, K.J.R., "Power controlled channel allocation for multiuser multiband UWB systems," *Wireless Communications, IEEE Transactions on* , vol.6, no.2, pp.583,592, Feb. 2007
[21] Hongseok Kim; Chan-Byoung Chae; de Veciana, G.; Heath, R.W., "Energy-efficient adaptive MIMO systems leveraging dynamic spare capacity," *Information Sciences and Systems, 2008. CISS 2008. 42nd Annual Conference on* , vol., no., pp.68,73, 19-21, March 2008
[22] Nilesh Mishra, Kameswari Chebrolu, Bhaskaran Raman, and Abhinav Pathak. 2006. Wake-on-WLAN. In *Proceedings of the 15th international conference on World Wide Web* (WWW '06)

References (Cont.)

[23] N. Blackmore. (2014, July) Wireless internet router is expensive on standby but is it wise to turn off at night? Accessed: Dec. 4, 2014. [Online]. Available: http://www.telegraph.co.uk/finance/personalfinance/money-saving-tips/10953517/Wireless-internet-router-is-expensive-on-standby-but-is-it-wise-to-turn-off-at-night.html

[24] Tauber, M.; Bhatti, S.N.; Yi Yu, "Towards energy-awareness in managing wireless LAN applications," *Network Operations and Management Symposium (NOMS), 2012 IEEE* , vol., no., pp.453,461, 16-20 April 2012

[25] Anand Vardhan Bhalla and Mudit Ratana Bhalla. Article: Generations of Mobile Wireless Technology: A Survey. *International Journal of Computer Applications* 5(4):26–32, August 2010. Published By Foundation of Computer Science

[26] J. Wannstrom. (2013, June) LTE-Advanced. [Online]. Available:http://www.3gpp.org/technologies/keywords-acronyms/97-lte-advanced

[27] I. F. Akyildiz, D. M. Gutierrez-Estevez, and E. C. Reyes, “The evolution to 4G cellular systems: LTE-Advanced,” Physical Communication, vol. 3, pp. 217–244, Mar 2010.

[28] Haeyoung Lee; Vahid, S.; Moessner, K., "A Survey of Radio Resource Management for Spectrum Aggregation in LTE-Advanced," *Communications Surveys & Tutorials, IEEE* , vol.16, no.2, pp.745,760, Second Quarter 2014

[29] Y. Wang, K. Pedersen, P. Mogensen, and T. Sorensen, “Carrier load balancing methods with bursty traffic for lte-advanced systems,” in Personal, Indoor and Mobile Radio Communications, 2009 IEEE 20th International Symposium on, pp. 22 –26, sept. 2009

[30] K. Pedersen, F. Frederiksen, C. Rosa, H. Nguyen, L. Garcia, and Y. Wang, “Carrier aggregation for lte-advanced: functionality and performance aspects,” Communications Magazine, IEEE, vol. 49, pp. 89–95, june 2011.

[31] H. Tian, S. Gao, J. Zhu, and L. Chen, “Improved component carrier selection method for non-continuous carrier aggregation in lte-advanced systems,” in Vehicular Technology Conference (VTC Fall), 2011 IEEE, pp. 1 –5, sept. 2011

[32] L. Zhang, F. Liu, L. Huang, and W. Wang, “Traffic load balance methods in the lte-advanced system with carrier aggregation,” in Communications, Circuits and Systems (ICCCAS), 2010 International Conference on, pp. 63 –67, july 2010.

[33] L. Lei and K. Zheng, “Performance evaluation of carrier aggregation for elastic traffic in lte-advanced systems,” IEICE Transactions, pp. 3516–3519, 2009.

References (Cont.)

[34]] L. Zhang, K. Zheng, W. Wang, and L. Huang, "Performance analysis on carrier scheduling schemes in the long-term evolution-advanced system with carrier aggregation," Communications, IET, vol. 5, pp. 612 –619, 2011.
[35] Q. Europe, "LTE-A MC RF requirements for contiguous carriers," TR R4-091910, 3GPP TSG-RAN WG4 51, Apr. 2009
[36] H. Wang, C. Rosa, and K. I. Pedersen, "Performance analysis of downlink inter-band carrier aggregation in lte-advanced.," in VTC Fall, pp. 1–5, IEEE, 2011
[37] L. Liu, M. Li, J. Zhou, X. She, L. Chen, Y. Sagae, and M. Iwamura, "Component carrier management for carrier aggregation in lte-advanced system," in Vehicular Technology Conference (VTC Spring), 2011 IEEE 73rd, pp. 1 –6, May 2011.
[38] A. Mihovska, "Spectrum aggregation with optimal multi-band scheduling," Wireless Personal Multimedia Communications Symposia. Proceedings, vol. 2010, pp. S11–4, 2010.
[39] X. Cheng, G. Gupta, and P. Mohapatra, "Joint carrier aggregation and packet scheduling in LTE-Advanced networks," in Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks, New Orleans, LA, June 24-27, 2013, pp. 469–477
[40] Ixia. (2013, Dec) Quality of service (QoS) and policy management in mobile data networks. White Paper, Accessed: July 10, 2014. [Online]. Available: http://www.ixiacom.com/sites/default/files/resources/whitepaper/policy_management.pdf
[41] Christian Bettstetter. 2001. Mobility modeling in wireless networks: categorization, smooth movement, and border effects. *SIGMOBILE Mob. Comput. Commun. Rev.* 5, 3 (July 2001), 55-66
[42] Christian Esteve Rothenberg, Andreas Roos, "A Review of Policy-Based Resource and Admission Control Functions in Evolving Access and Next Generation Networks", Journal of Network and Systems Management March 2008, Volume 16, Issue 1, pp 14-45
[43] J. Gubbi, R. Buyya, S. Marusic, M. Palaniswami, Internet of things (IoT): A vision, architectural elements, and future directions, Future Generation Computer Systems 29 (2013) 1645 – 1660.
[44] F. Richter, Smartphone sales break the billion barrier, 2013. Accessed: June 12, 2014
[45] http://www.3gpp.org/technologies/keywords-acronyms/101-carrier-aggregation-explained
[46] http://www.ntt.co.jp/news2012/1209e/120920a.html