PhD Defense

Design and Development of Carrier Assignment and Packet Scheduling in LTE-A and Wi-Fi

Husnu S. Narman

Outline

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

Wireless Communication

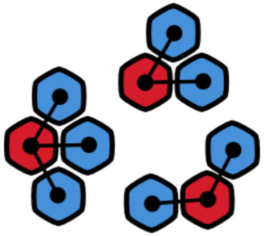
- A process by which information is exchanged between devices through a common system of signals over a frequency or band

Multi-band Wireless Communication

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

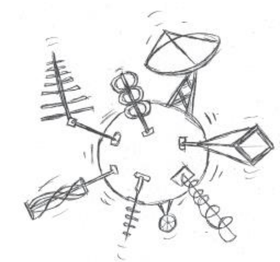
Factors of Multi-band Wireless Communication[1]

- Devices
  - Different devices (support single or multi band)
- Users
  - User profile (teenager, businessman) and a 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)

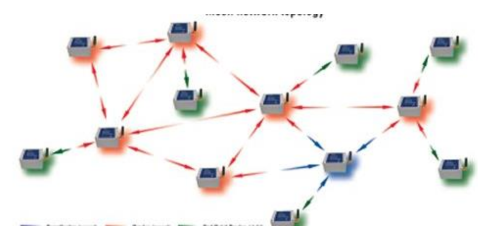


Challenges

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



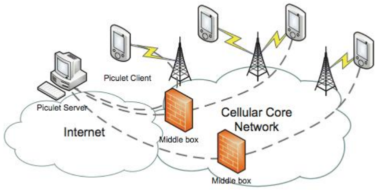
- Channel deployment[4]



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

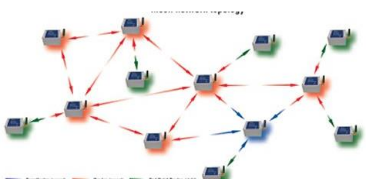
Applications of Multi Band Wireless Communication

- Cellular networks
  - LTE-A[7]



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

- Sensor networks[4]



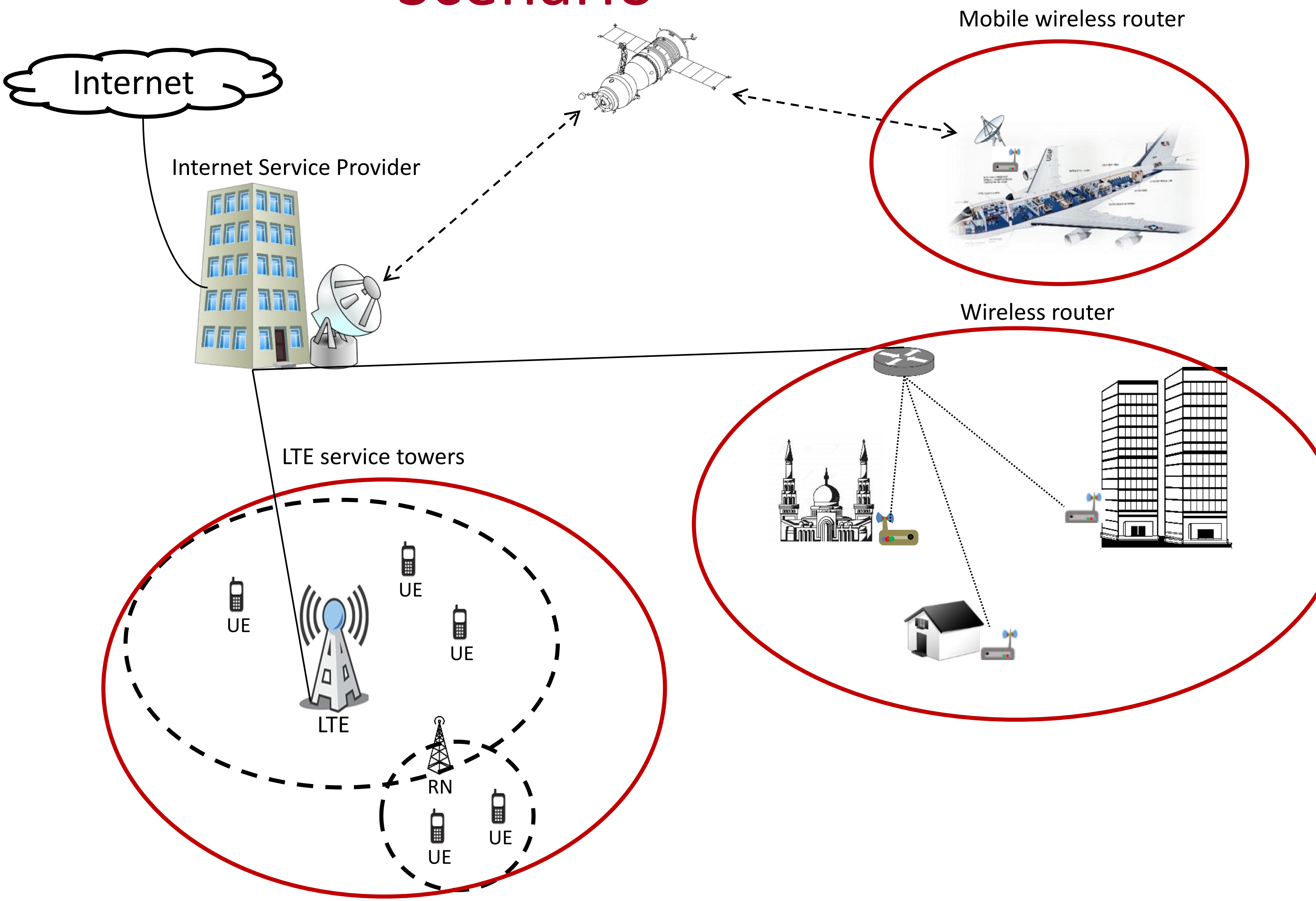
- Radar[9]

Objective

- Analysis of multi-band communication in LTE-A and Wi-Fi

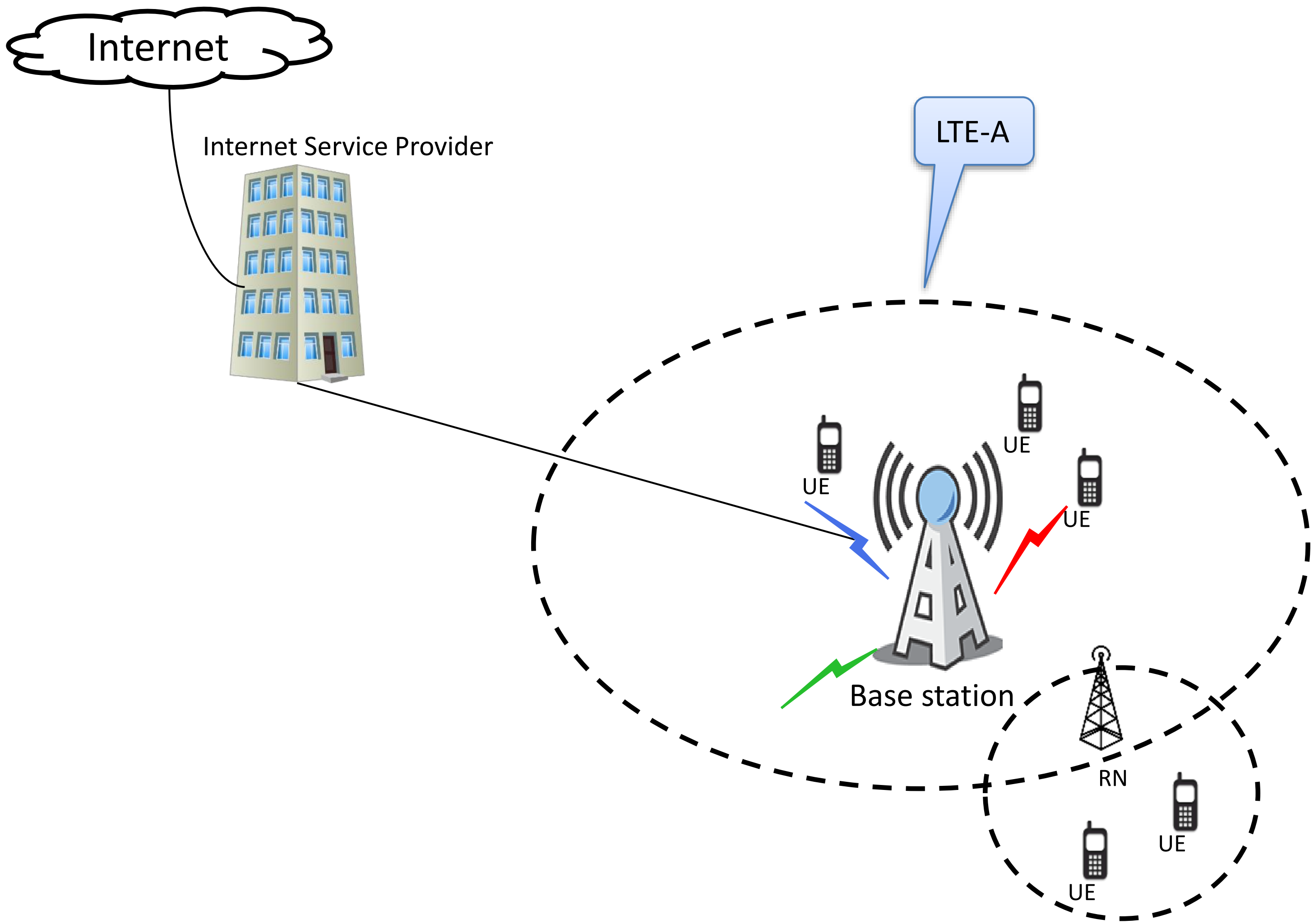
- Increasing performances of LTE-A and Wi-Fi by developing resource allocation and scheduling methods

Scenario


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

Multi-band Communication in LTE-A

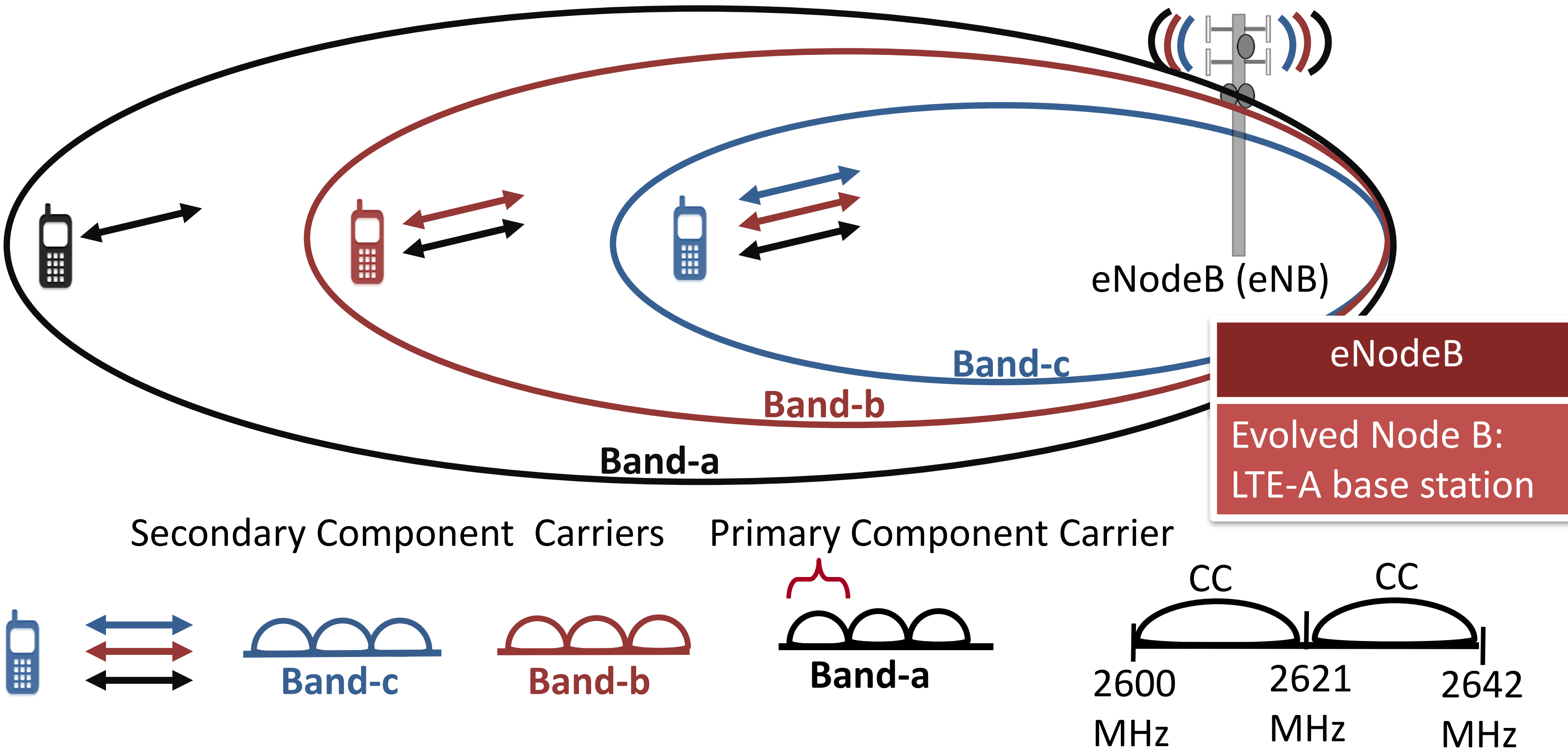
Scenario: LTE-A



LTE and LTE-A

	4G/LTE	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]



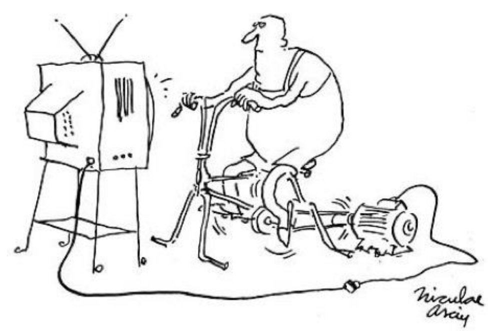
Up to 5 Component Carriers (CC) for downlink and uplink

Introduction
objective
LTE-A
Wi-Fi
Conclusion

Key Challenges[27][28]

- Balancing user loads to bands

- Satisfying users
- Resource usage efficiency
  - Bandwidth
  - Power

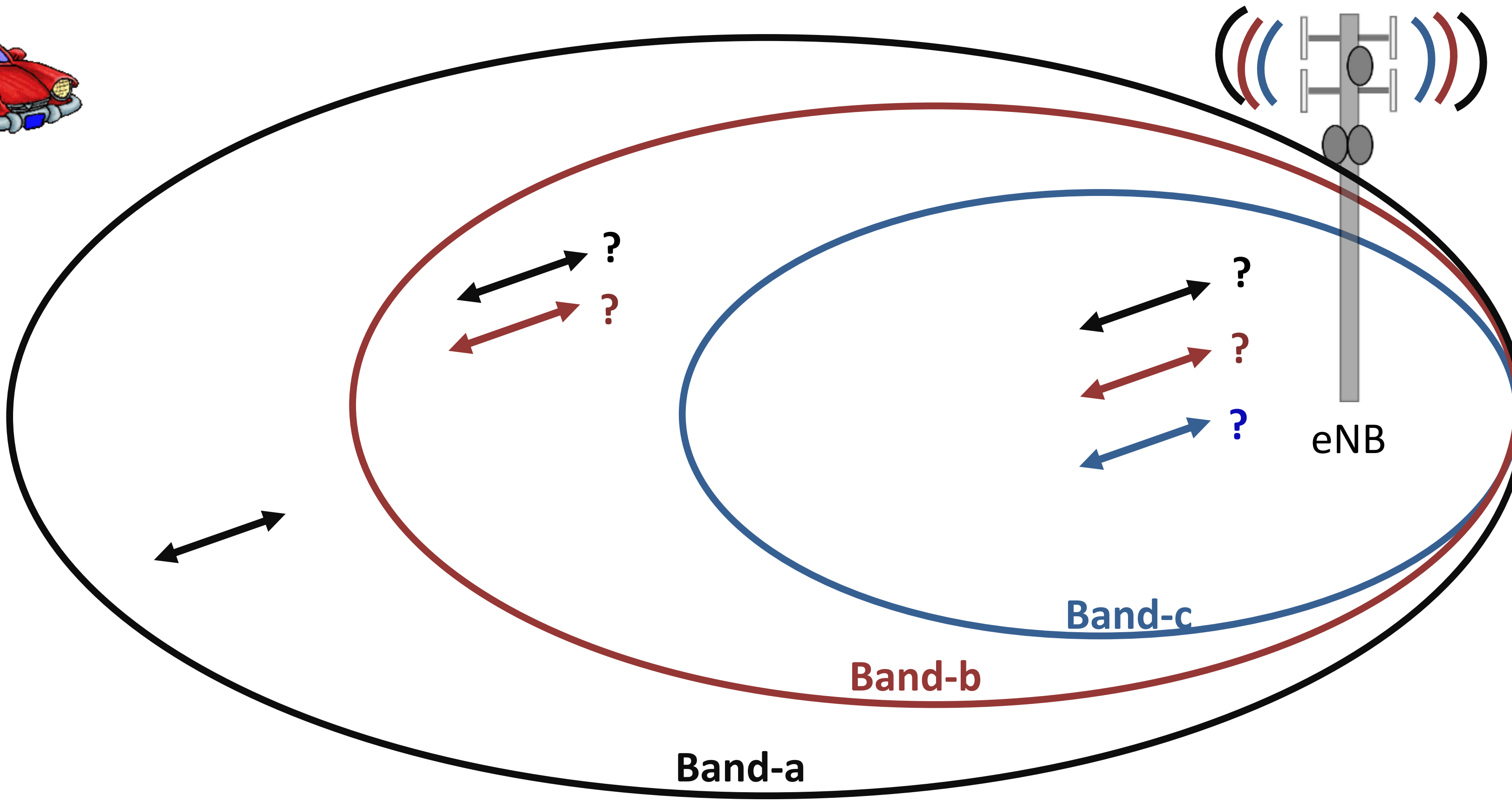


First Problem Statement

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

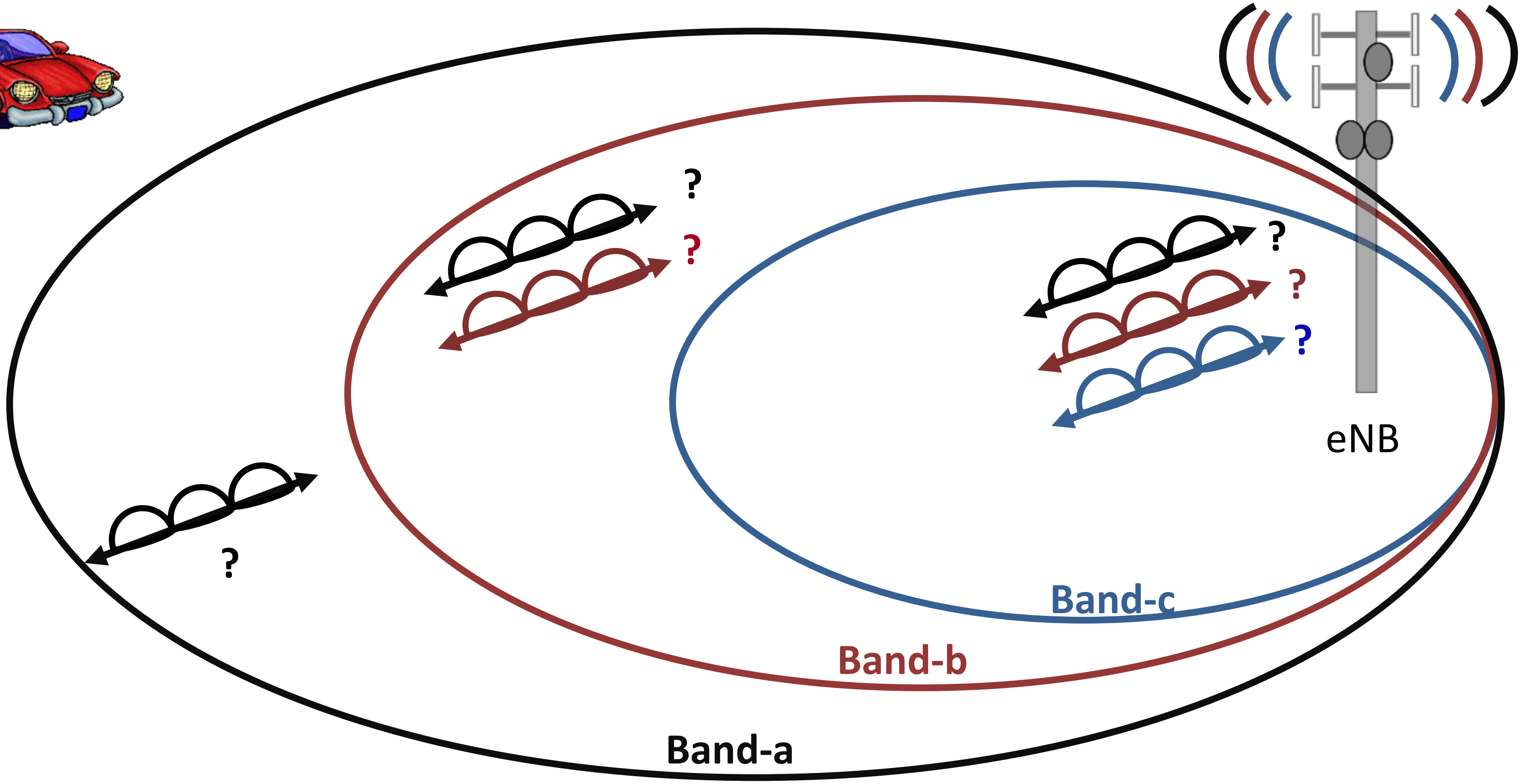
First Example

Which bands should eNB assign to each user?



Second Example

How many CCs should be assigned to each user?

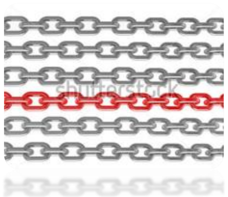


Current Solutions

- 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

Why need another Carrier Assignment Method?

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

- To measure the number of required Component Carriers

Why: Carrier Assignment Based on User Profile[40][42]

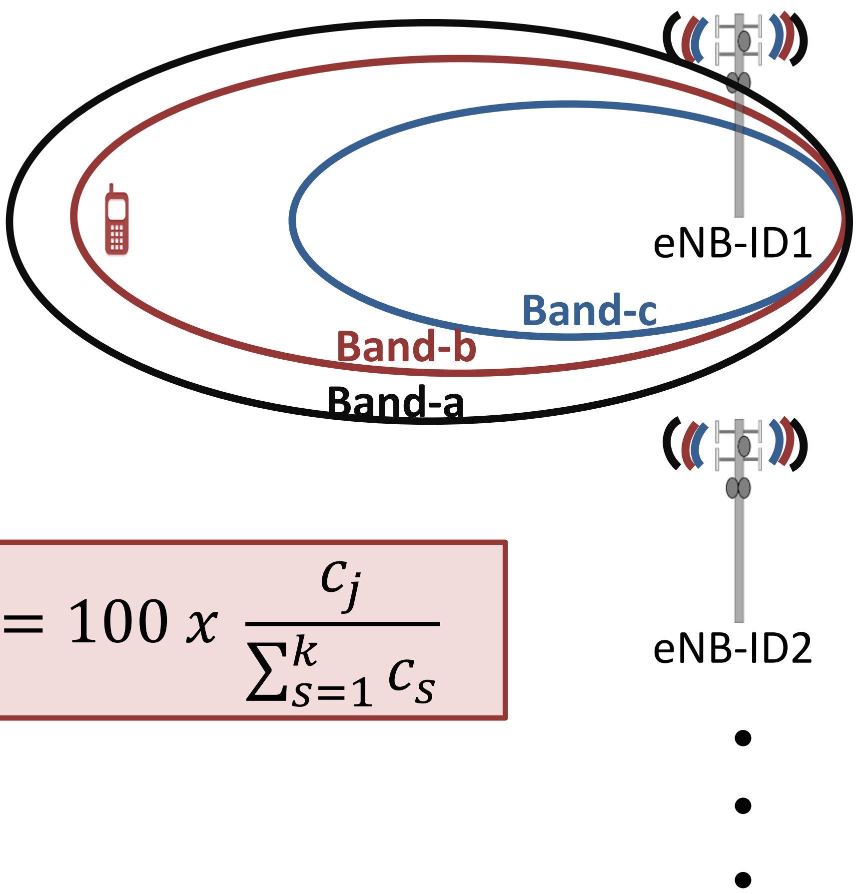
			User Profile				
			UE_1 (Teenager)	UE_2 (Housewife)	UE_3 (Businessman)	UE_4 (G. Student)	UE_5 (Grand Parent)
Traffic Types	RT	Video	Very High	Middle	Low	Medium	Low
		Online game	Very High	Low	Low	Medium	Low
		Movie	Very High	Very High	Low	Medium	Low
		Talk	Low	Medium	High	Medium	Very High
	NRT	Web	High	Low	Very High	Medium	Low
		E-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

Proposed: Carrier Assignment Based on User Profile

- Depends on
  - Type of used equipment
  - User behaviors
  - Load balance techniques
  - Channel Quality Indicator (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:

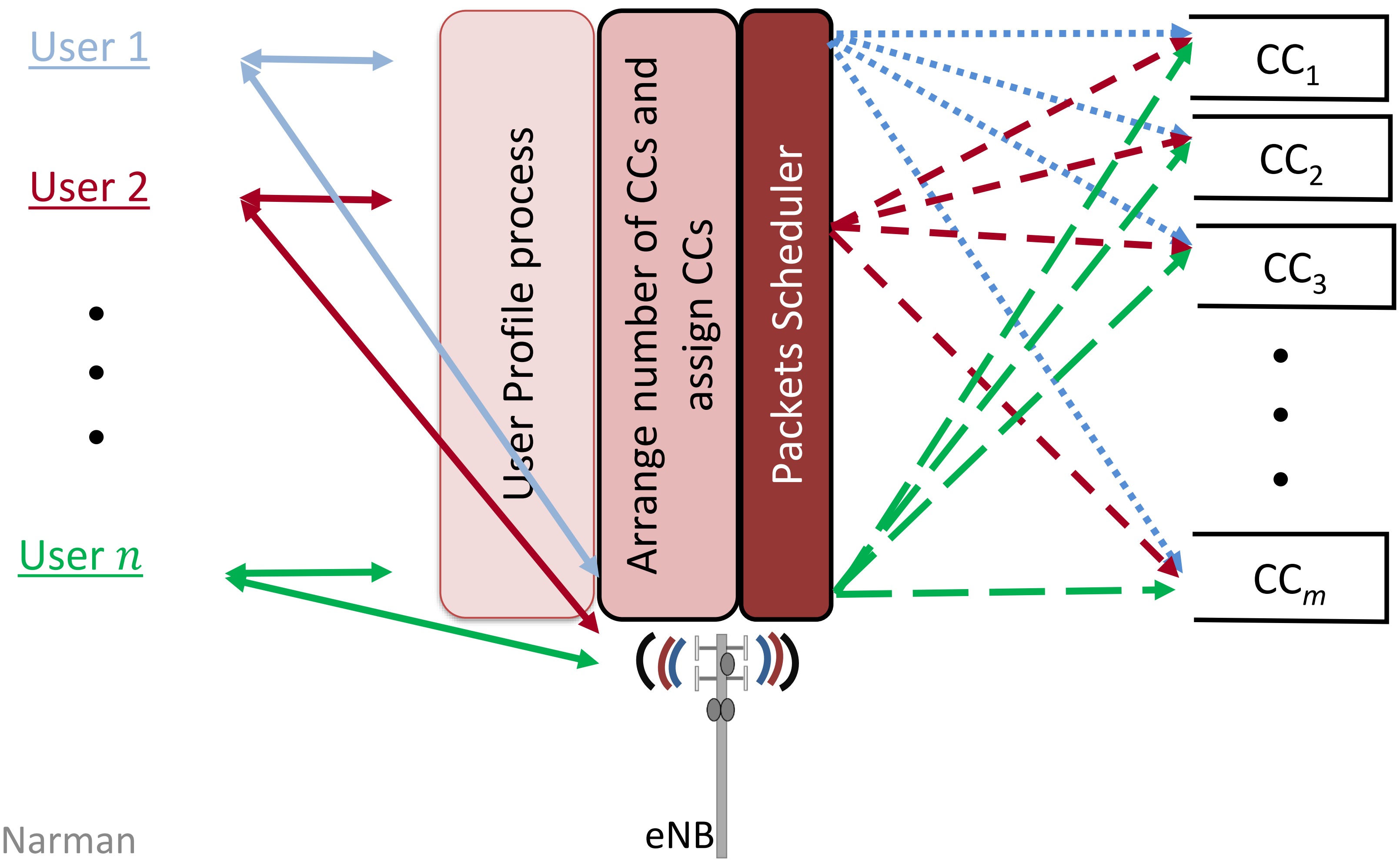
$$T_j = 100\ x\ \frac{f_j}{\sum_{s=1}^{k} f_s}$$

$$C_j = 100\ x\ \frac{c_j}{\sum_{s=1}^{k} c_s}$$

Examples

- Case1: Higher C and lower T
- Case2: Lower C and higher T

Carrier Assignment Based on User Profile



Carrier Assignment Based on User Profile (Cont.)

Getting user device info → List available CCs based on CQI and LB → Determining CCs and number of CCs → Assign CCs to user → Start Packet scheduling over CCs

LTE and LTE-A

The number of available CCs

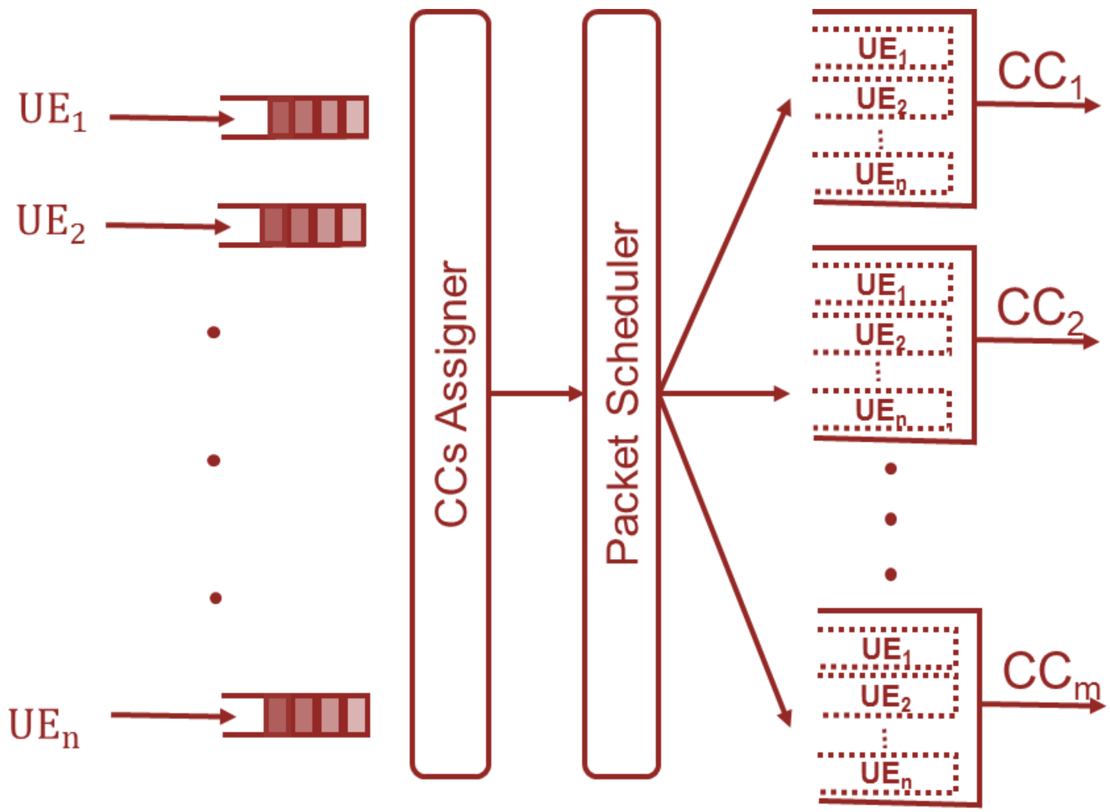
Developed formulas are used

$$number\ of\ CC = Average\ data\ usage\ of\ the\ user / \ CC\ service\ rate$$

$$CC\ selection = \text{Active connected service time per connection} * \frac{CC\ service\ rate}{Data\ usage\ of\ active\ users\ in\ a\ band}$$

Queue Packet Scheduling

Disjoint Queue Scheduler



Simulation Environments

Scenario [42]	b
Number of eNB	1
Used Bands	800MHz, 1.8GHz, 2.6GHz
Number of CCs in Each Band	4
Total Number of CCs	12
Queue Length of Each Queue	50 packets
Bandwidth of CCs	10MHz
Modulations	QPSK, 16QAM, and 64QAM
CQI	3, 5, 7, and 11
Transmission Time Interval	10ms (10ms is average, it can be more or less)
Time for CCA	20ms (at most 20ms)
CQI Threshold	The highest possible
Simulation Model	Finite buffer [102]

- LTE (1 CC), LTE-A (4 CCs)
- Users are non-uniformly distributed and half of users is LTE-A type.
- 50% users are freely move around of the eNB.
- Min-delay packet scheduling.
- Packet arrival follows Pareto with increasing packet arrival rate.

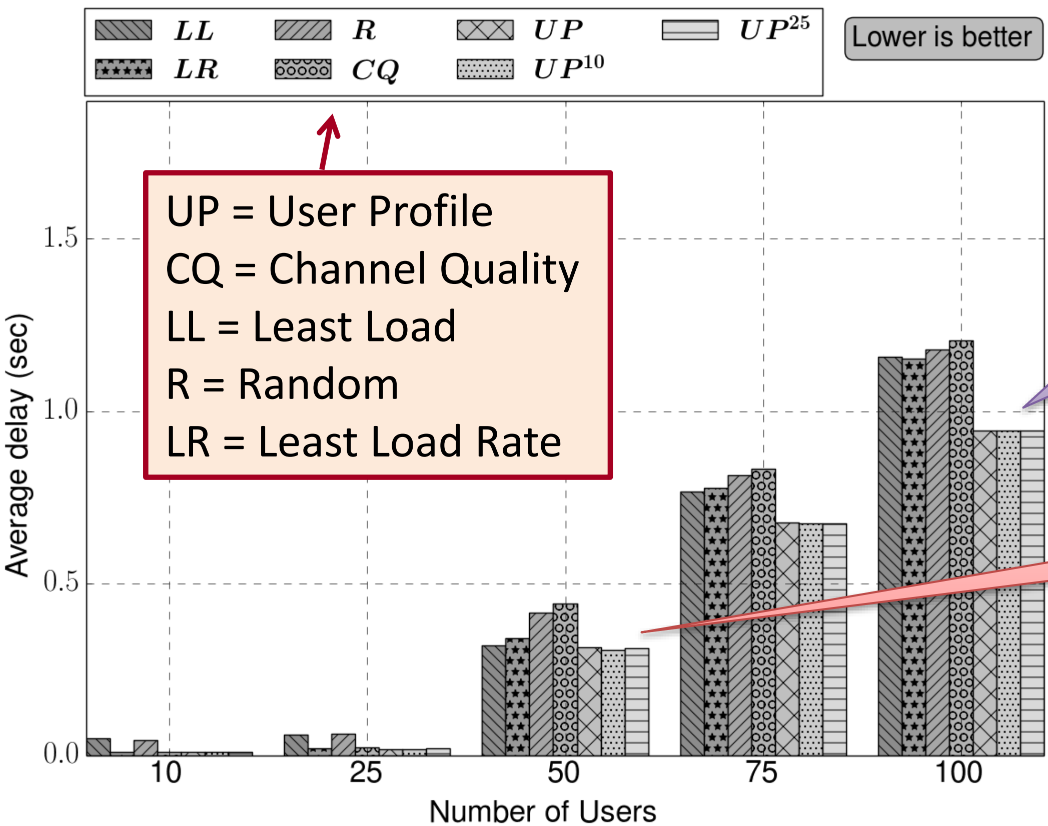
Results-Average Delay

Average Delay

The average waiting time of transferred packets in the queues and service.

Objective

Observing effects of the number of users on average delay.



Delay of the proposed method is lower.

The differences between UP, UP^{10} and UP^{25} are insignificant.

UPs can decrease delay up to 20%.

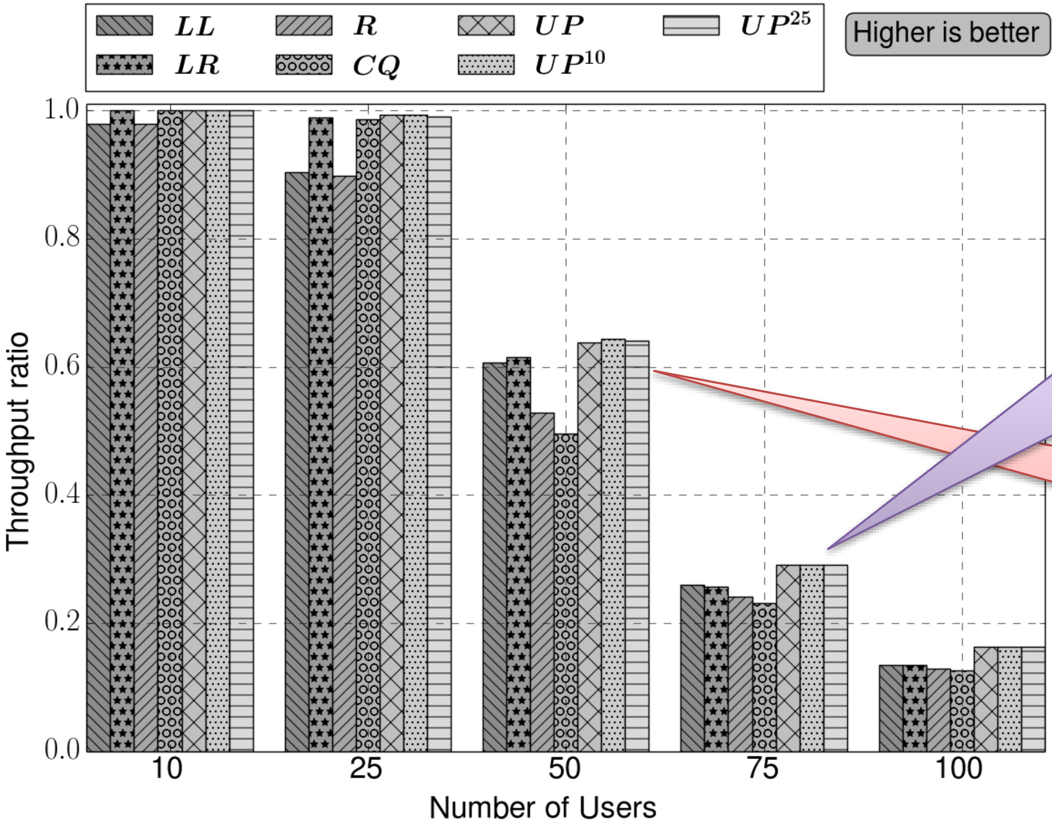
Results-Throughput Ratio

Throughput Ratio

Ratio of the successfully transferred packets to total processed packets.

Objective

Observing effects of the number of users on throughput ratio.



Throughput ratio of the proposed method is higher.

The differences between UP, UP10 and UP25 are insignificant.

UPs can increase throughput ratio up to 15%.

Improvements: User Profile

Improving throughput ratio up to 15%.

User Profile

Security concern

Delay time can be decreased up to 20% .

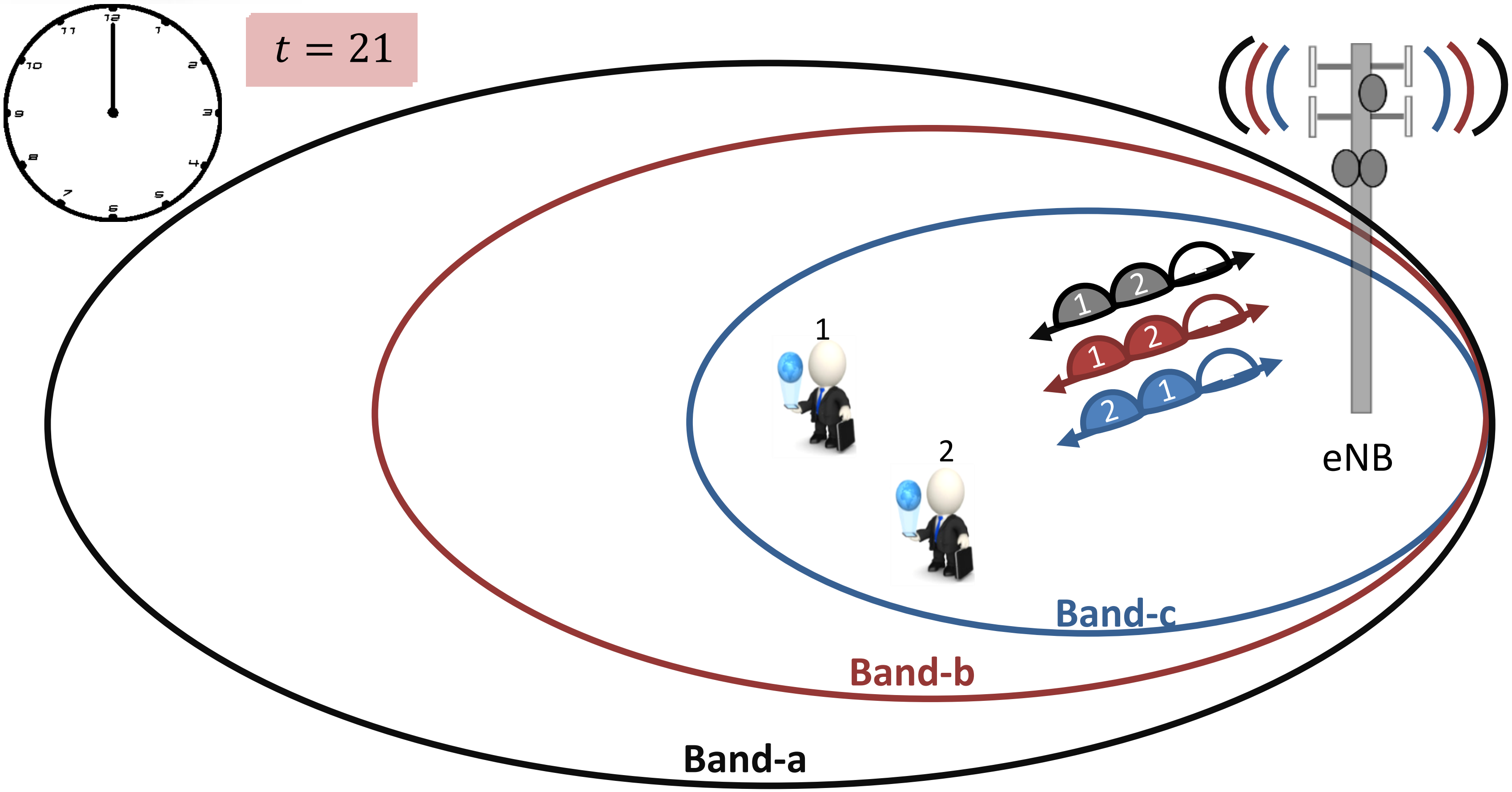
Periodic Carrier Assignment

- Periodic Carrier assignment Method is developed[39].
  - Periodically occurs in addition to mandatory reasons.
  - Carrier assignment methods are analyzed according to overall system performance.

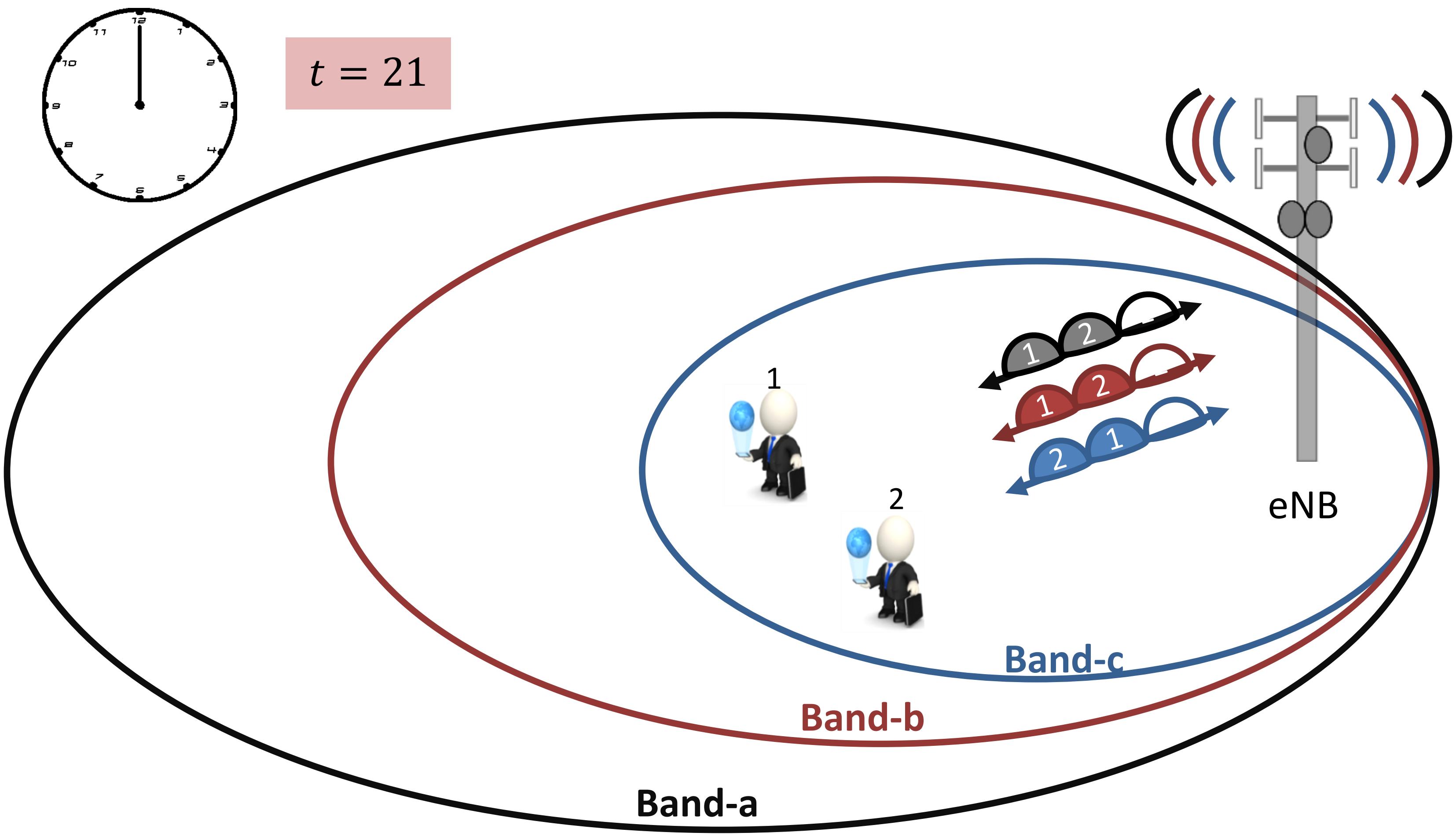
[39] X. Cheng, G. Gupta, and P. Mohapatra, "Joint carrier aggregation and packet scheduling in LTE-Advanced networks," in Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks, New Orleans, LA, June 24-27, 2013, pp. 469–477

Sub-problem[39]

Periodic reassignment of component carriers jointly happened for all users?



Selective Periodic Assignment Technique

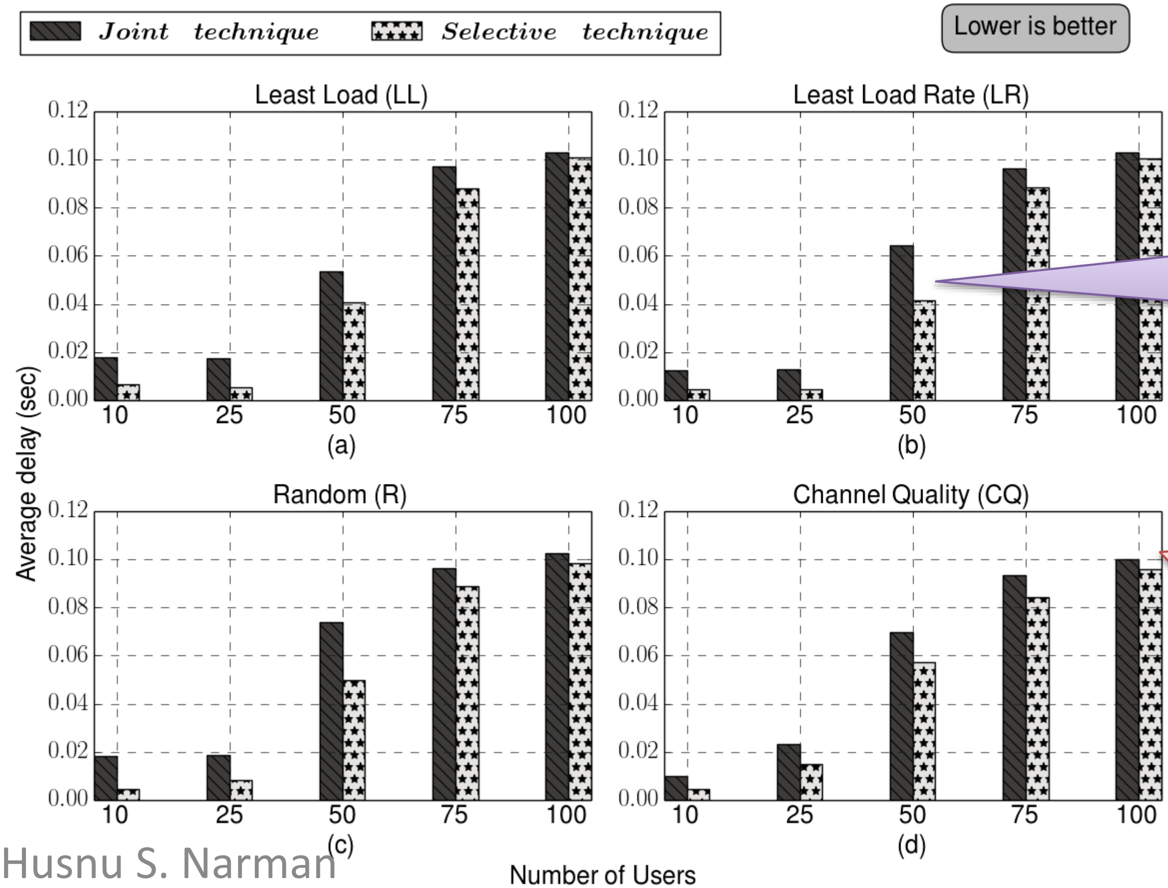


Average Delay during Carrier Assignment Operations

Average Delay
The sum of delay of packets during the carrier assignment operations is divided to the number of processed packets.

Objective
Observing effects of the number of users on average delay.

Lower is better



Delay of selective technique is lower than joint technique for all methods.

The delay differences between selective and joint techniques decrease for higher number of users.

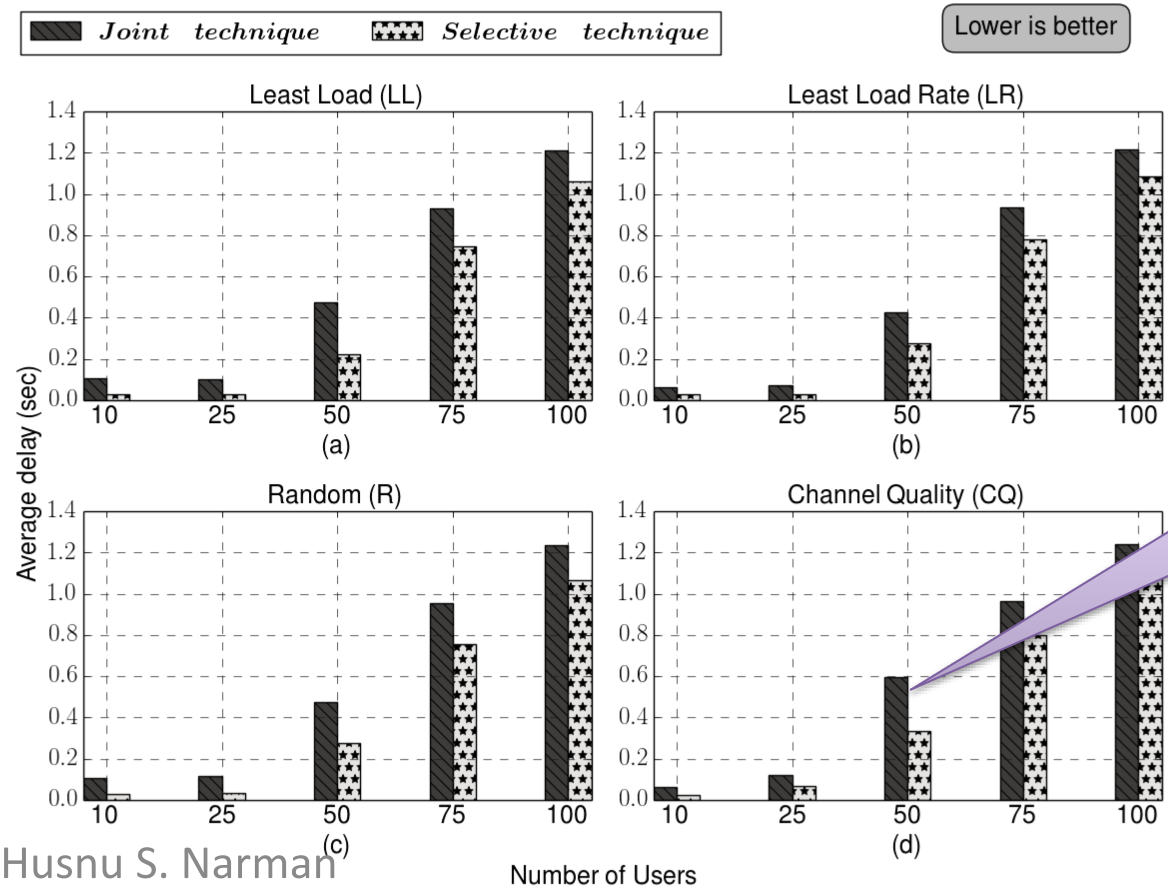
Overall Average Delay

Average Delay

The average waiting time of successfully transferred packets in the queues and service.

Objective

Observing effects of the number of users on average delay.



Overall delay of selective technique is lower than joint technique for all methods.

Selective technique can decrease overall average delay up to 50%.

Overall Throughput Ratio

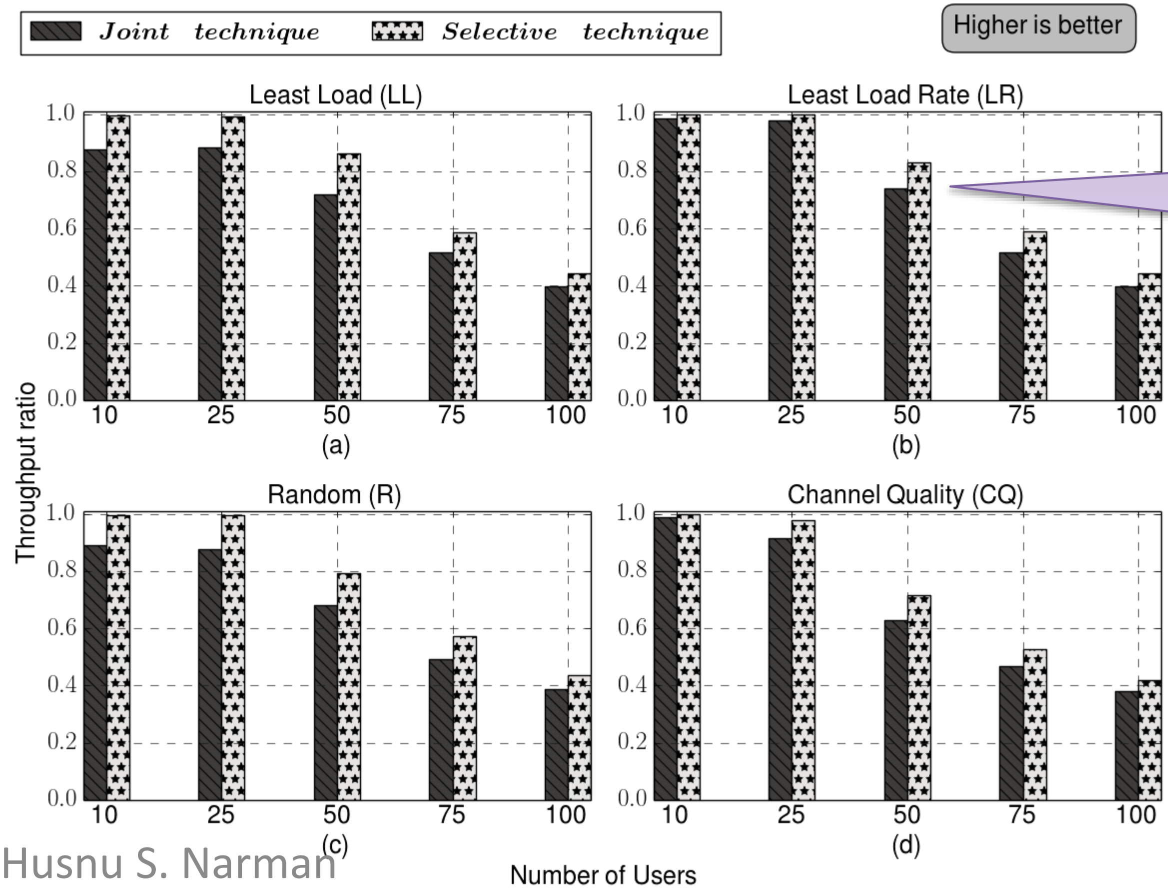
Throughput Ratio

Ratio of the successfully transferred packets to total processed packets.

Objective

Observing effects of the number of users on throughput ratio.

Higher is better



Throughput ratio of the selective technique is higher.

Selective technique can increase overall throughput ratio up to 18%.

Improvements: Selective CCs for Periodic Assignment

18%

Improving throughput ratio up to 18% comparing to joint periodic CCs assignment.

Selective-Periodic

Decreasing delay time up to 50% comparing to joint periodic CCs assignment.

50%

Summary of Contributions in LTE and LTE-A

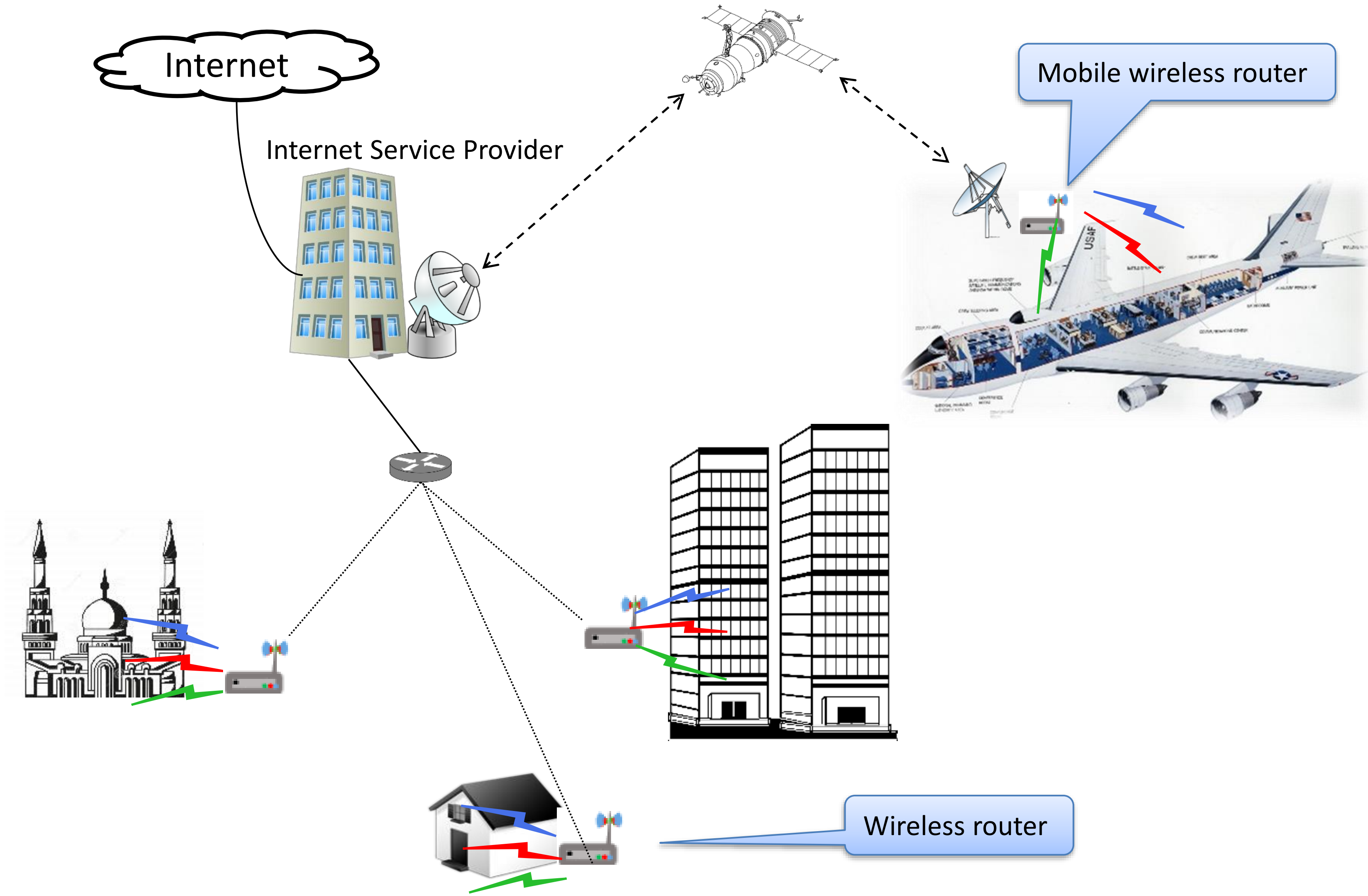
- A **novel carrier assignment method based on user profile** is proposed in LTE and LTE-A.
- **Selective technique** is developed for periodic CCs assignment.
- Performances of the proposed methods are evaluated according to the queue systems and extensive simulations.

Research Papers on Carrier Assignment in LTE-A

- [1] **H. S. Narman** and M. Atiquzzaman, ”Carrier components assignment method for LTE and LTE-A systems based on user profile and application,” IEEE GLOBECOM Workshop on Broadband Wireless Access, Austin, TX, Dec 12, 2014.
- [2] **H. S. Narman** and M. Atiquzzaman, ”Joint and partial carrier components assignment techniques based on user profile in LTE systems,” IEEE Wireless Communications and Networking Conference (WCNC), New Orleans, LA, Mar 9-12, 2015, pp. 983-988.
- [3] **H. S. Narman** and M. Atiquzzaman, ”Analysis of joint and partial component carrier assignment techniques in LTE and LTE-A,” IEEE Global Communications Conference (GLOBECOM), San Diego, CA, Dec 6-10, 2015.
- [4] **H. S. Narman** and M. Atiquzzaman, ”Selective periodic component carrier assignment technique in LTE and LTE-A systems,” IEEE Global Communications Conference (GLOBECOM), San Diego, CA, Dec 6-10, 2015.
- [5] **H. S. Narman** and M. Atiquzzaman, ”Joint and Selective Periodic Component Carrier Assignment Techniques for LTE-A,” Submitted to Elsevier Computer Networks, 2016.
- [6] **H. S. Narman** and M. Atiquzzaman, ”Carrier Components Assignment Method Based on User Profile in LTE and LTE-A,” Submitted to Springer Wireless Networks, 2016.

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

b
2.4 GHz
11 Mbps
DSSS

g
2.4 GHz
54 Mbps
DSSS,OFDM

n
2.4, 5 GHz
65, 135 Mbps
OFDM

Multi-band

ac
5 GHz
780 Mbps
OFDM

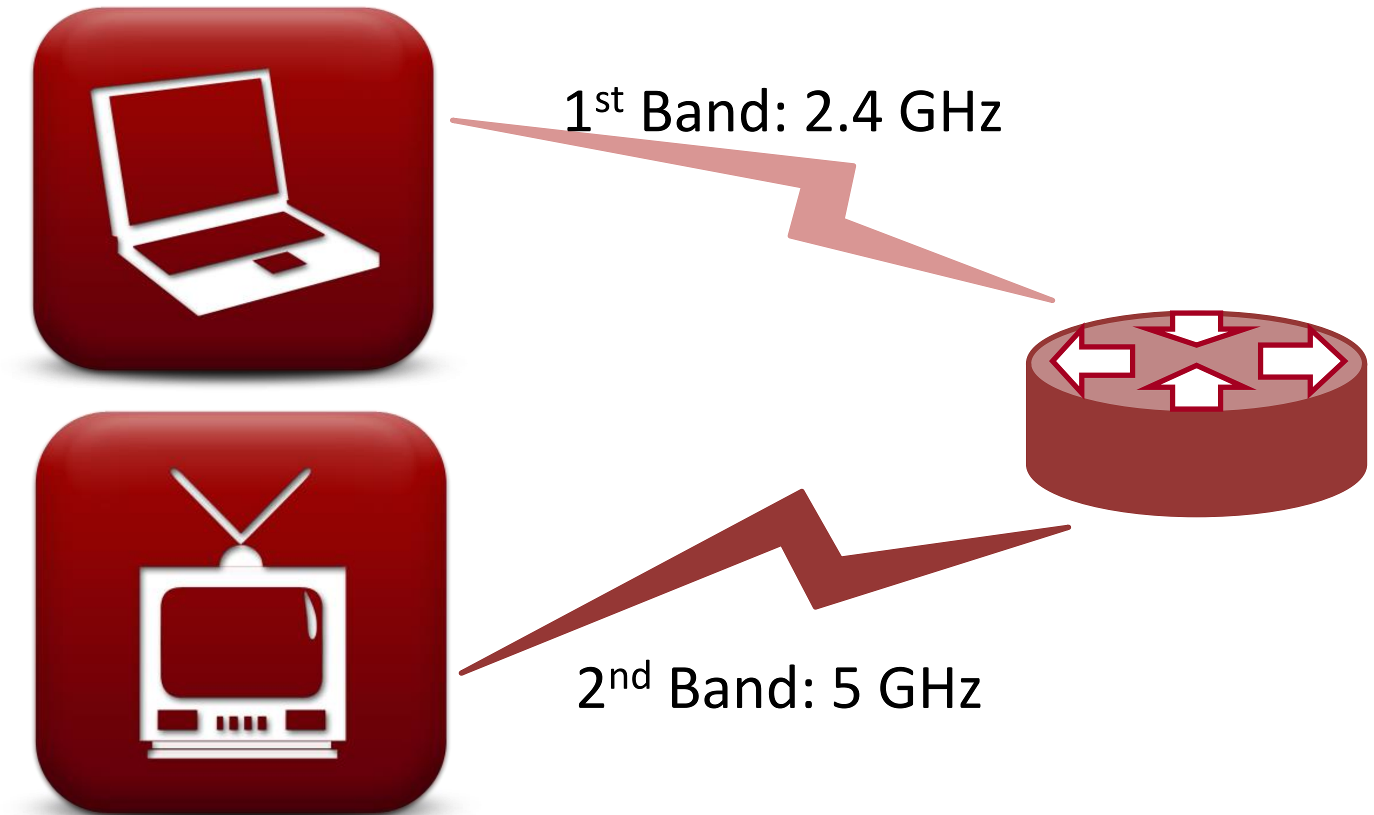
ad
2.4, 5, 60 GHz
7 Gbps
OFDM

Multi-band

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

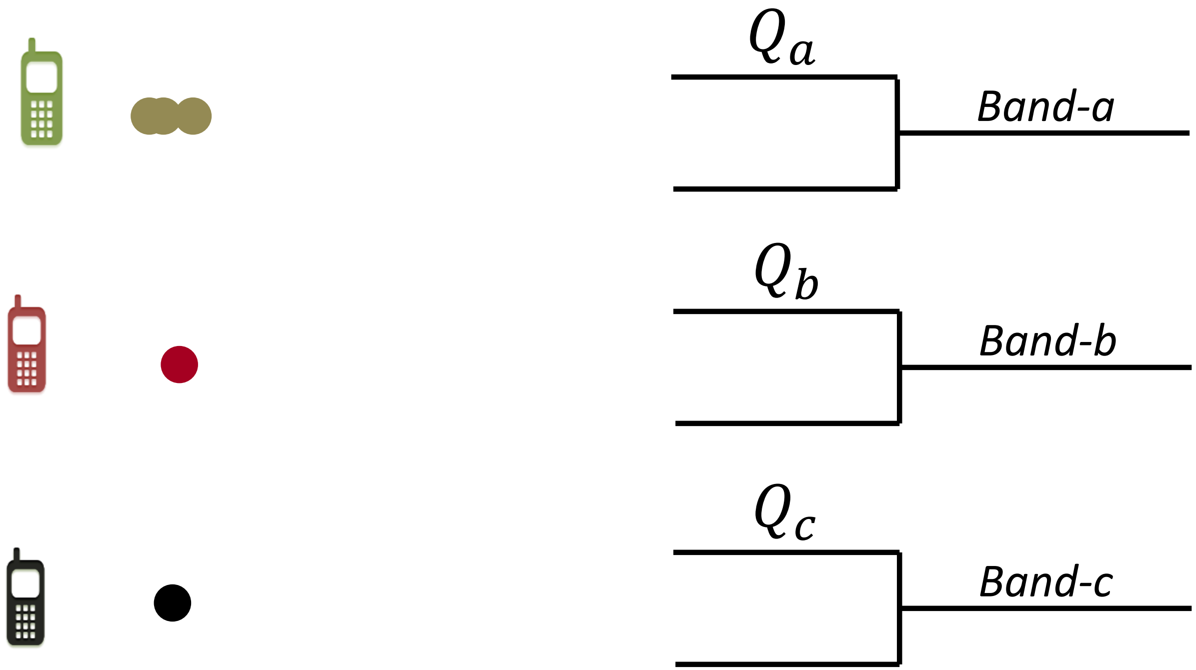
Multi-band

Current Multi Band (802.11n generation)[8]



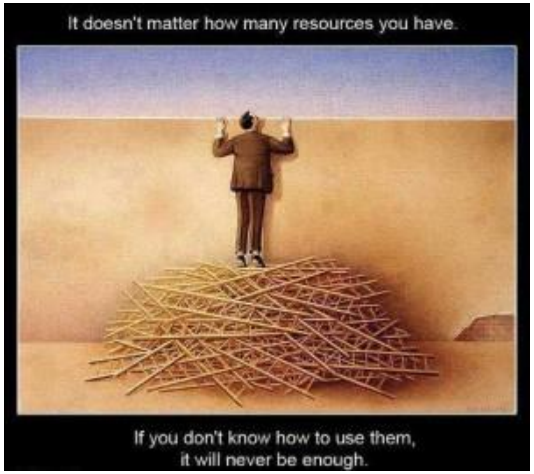
The benefit of using multi-band router is less interference, higher capacity and better reliability.

Current Multi-Band Queuing System[8]



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

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



Second Problem Statement

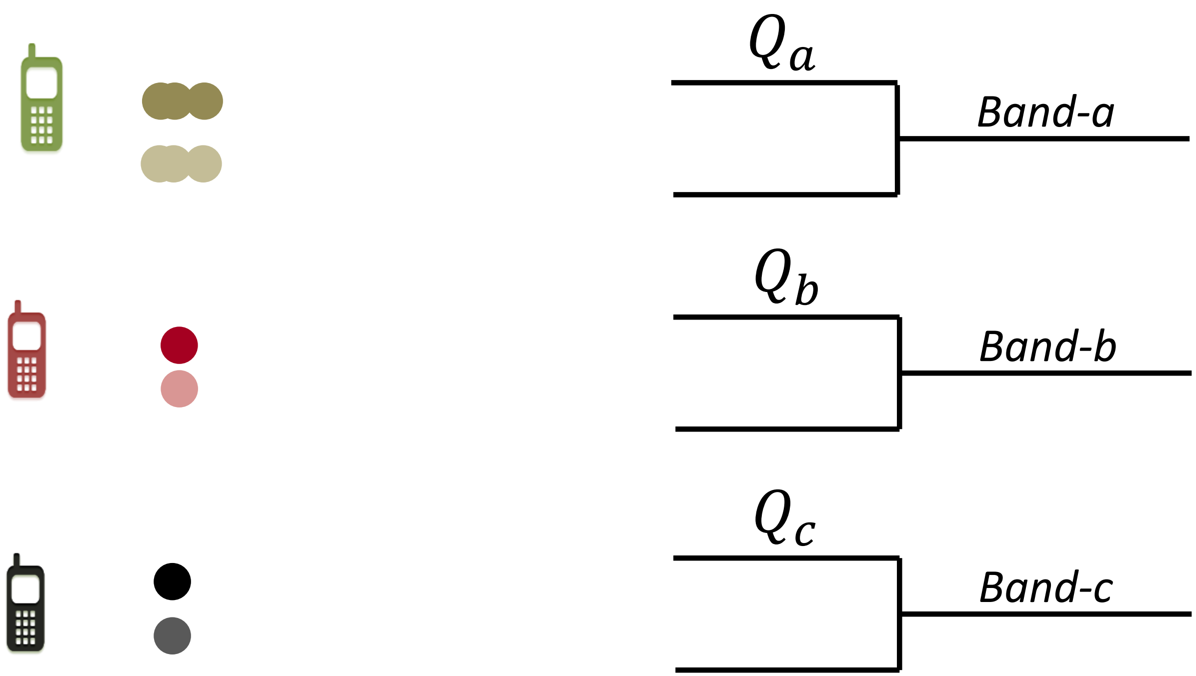
How to utilize bands of multi-band wireless routers and provide data traffic management based on the characteristics of bands

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

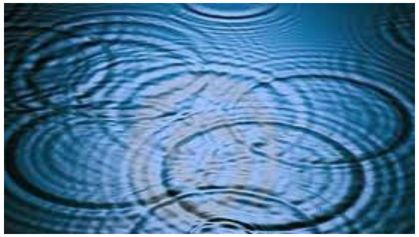
[8] http://grouper.ieee.org/groups/802/11/Reports/802.11_Timelines.htm
[11] http://www.cisco.com/c/en/us/td/docs/ios/12_2/qos/configuration/guide/fqos_c/qcfconmg.html

Current Multi-Band Priority Queuing System with Traffic Management

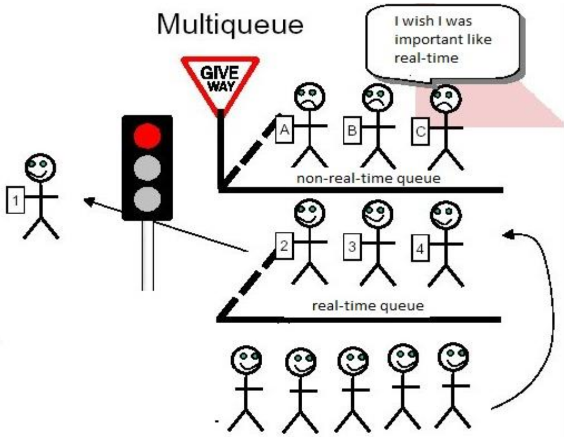


Disadvantages of Current Solutions

- 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 services
    - Threshold can be used for traffic service but finding optimum threshold is another problem



Disadvantages of Current Solutions

- Dynamic channel allocation is good for
  - Throughput
  - Data traffic management
  - But not band utilization
    - One band can be flooded with data but the others cannot.

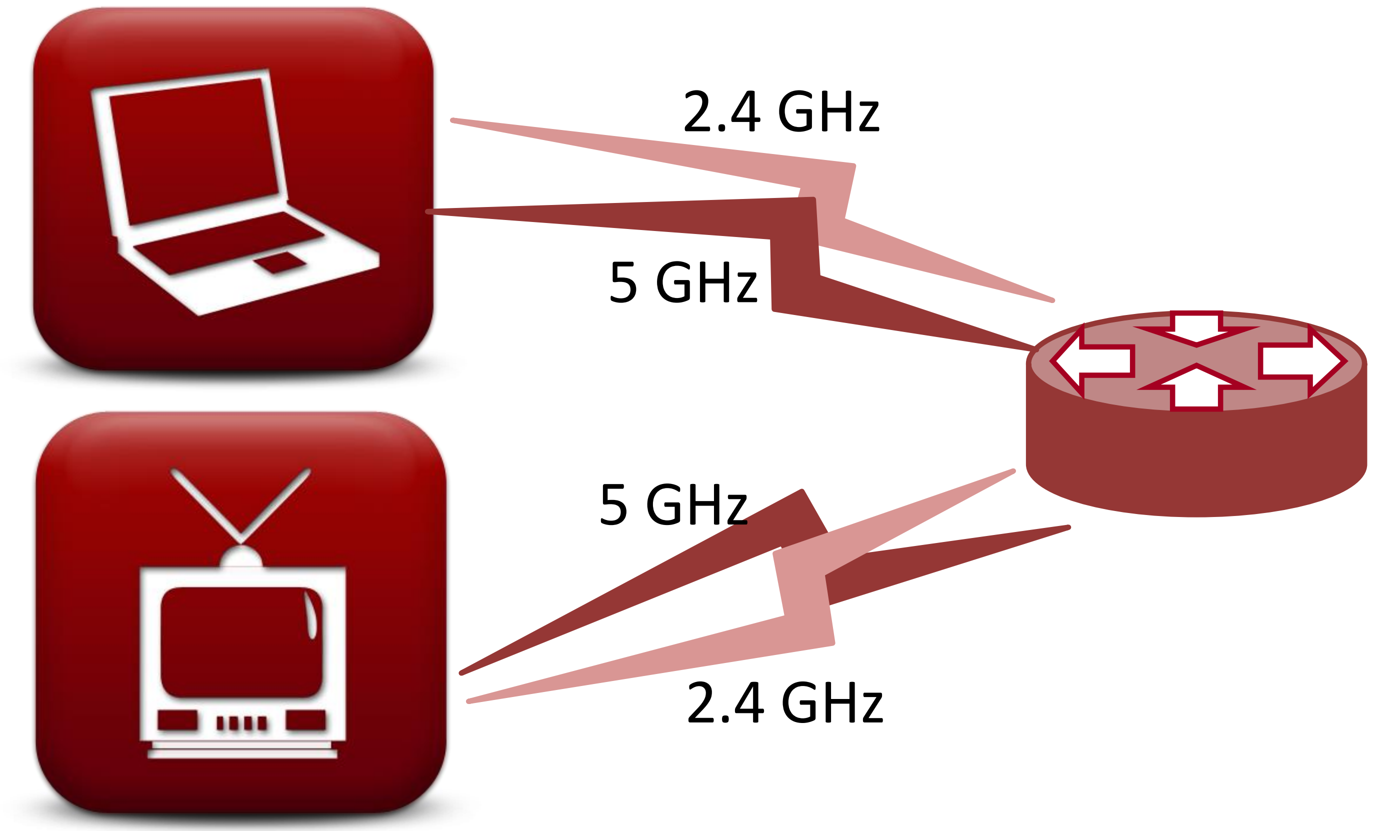
Why need another Router System

- 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.

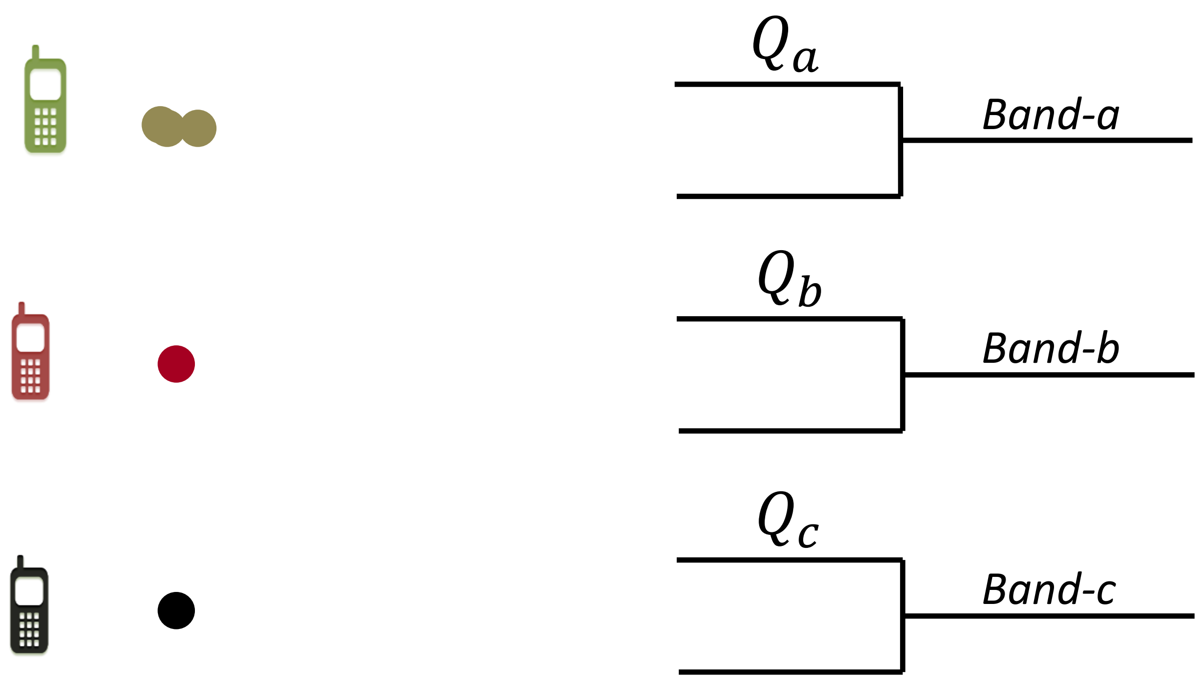
Reading and Idea

- 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]

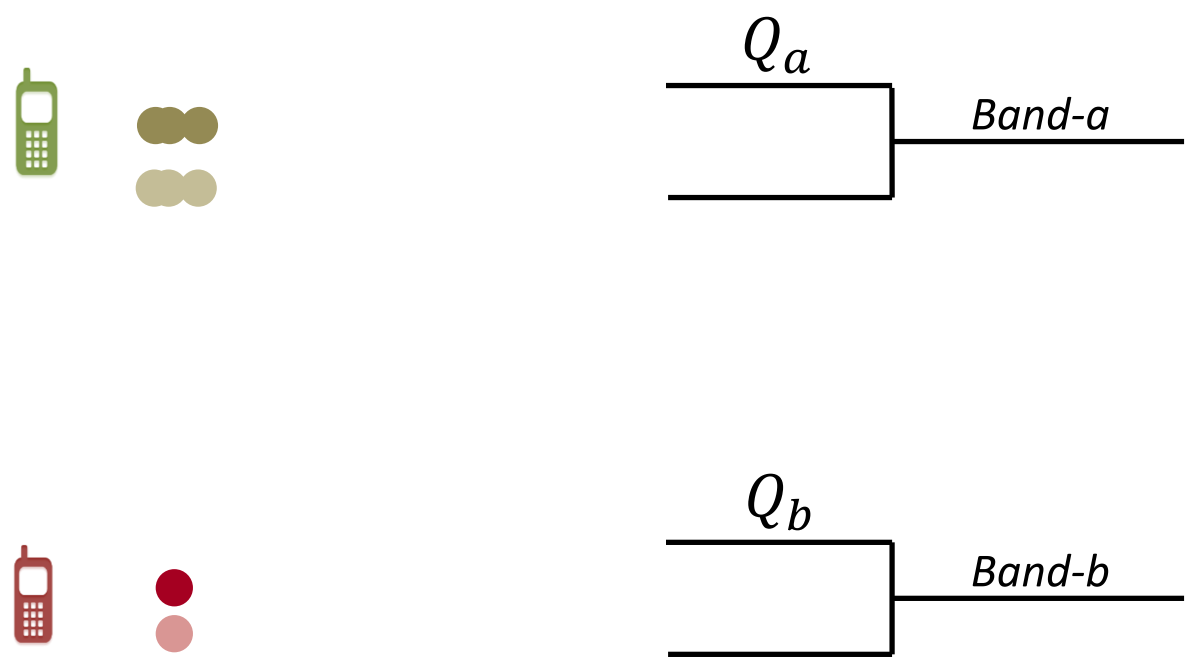
Proposed: Multi-shared-band Router



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

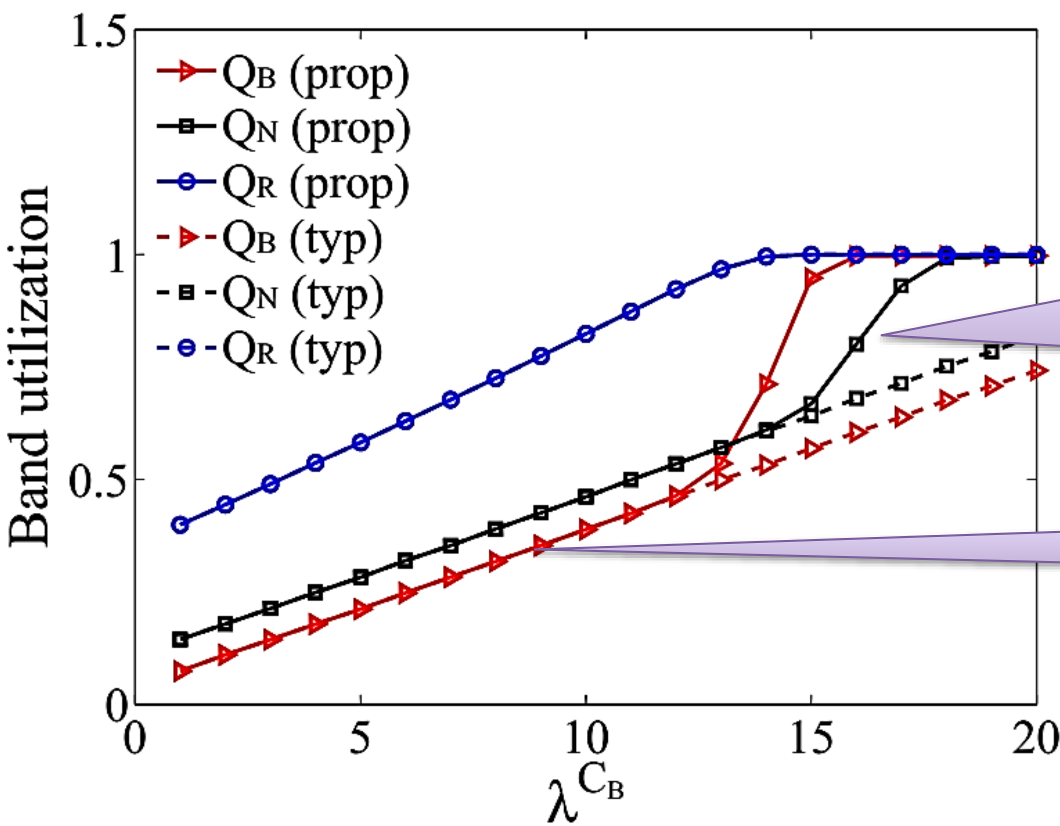
Results-Band Utilization

Band Utilization

The packet arrival rate is divided by service rate

Objective

Observing effects of lower and higher data traffic loads on band utilization.



Utilization of proposed method is higher when system is under heavy traffic load.

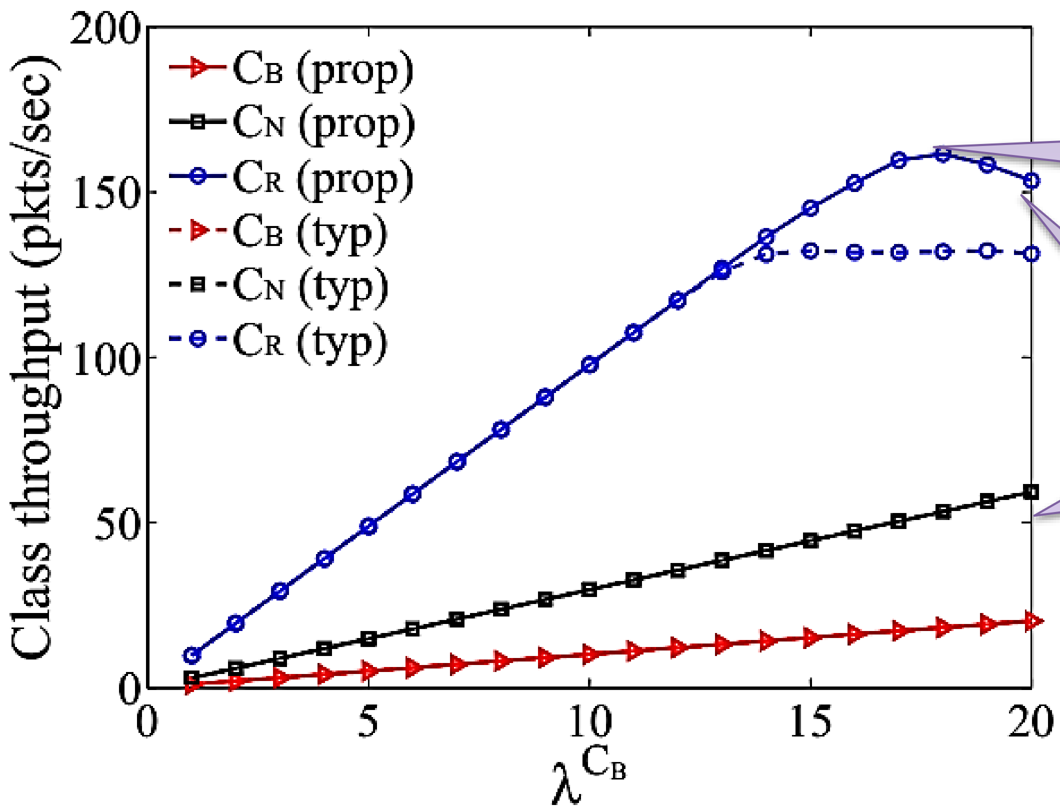
Utilization is same for low packet arrivals.

The proposed method utilizes the bands.

Results-Throughput

Throughput
The number of transferred packets in one second.

Objective
Observing effects of lower and higher data traffic loads on throughput.



Throughput of proposed method is higher.

Throughput of proposed method is decreasing when the packet arrival rates of the other data class traffic increase.

The proposed method has higher throughput.

Introduction
objective
LTE-A
Wi-Fi
Conclusion

Improvements: Multi-shared-band Router

23%

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

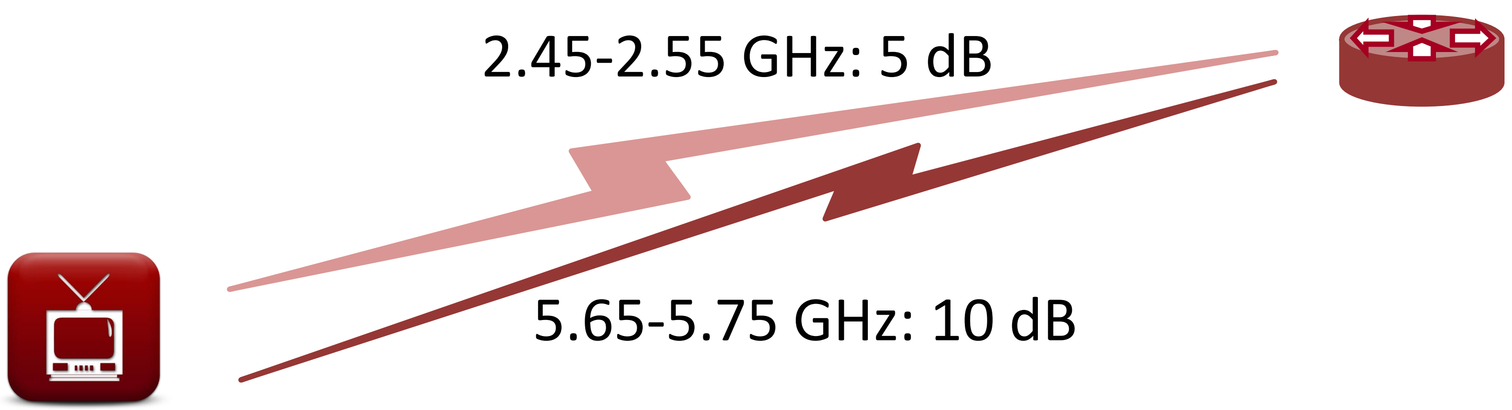
Multi-shared-band

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 Solutions for Sub-problem

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

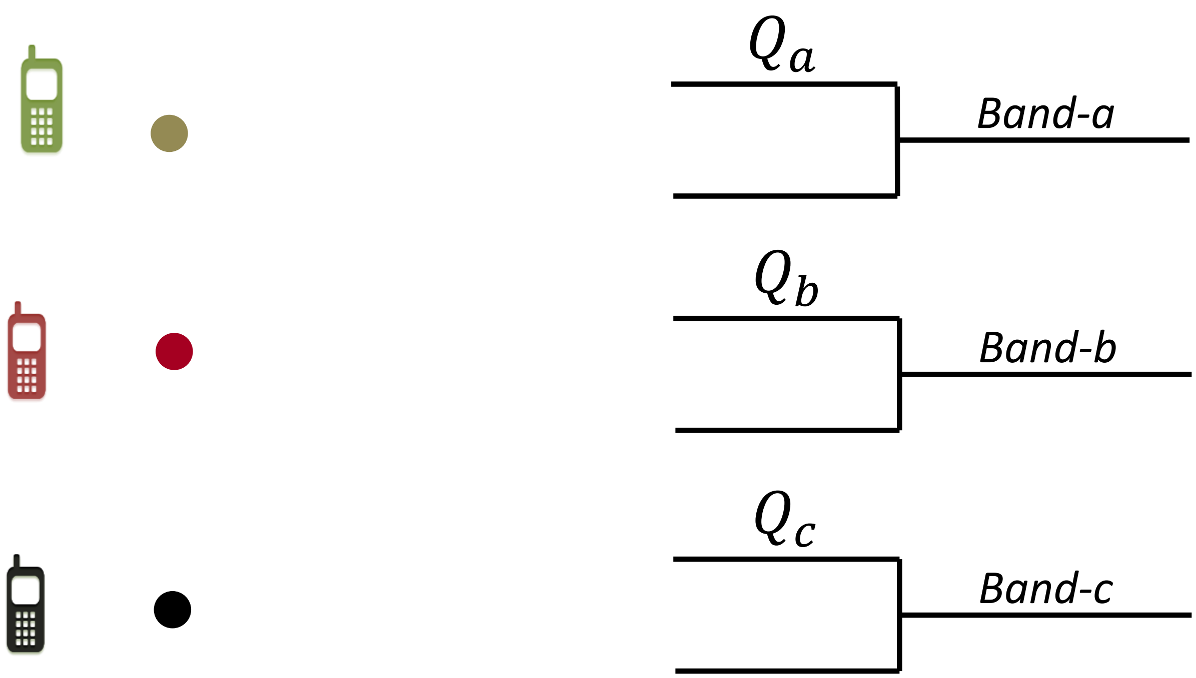


- Antenna Selection in MIMO[21]
  - Good for transferring data but not for stand by.
- Wake Sleep Procedure[22]
  - Small Amount of time in remote device (Not actual router)
- Using small packets[24]

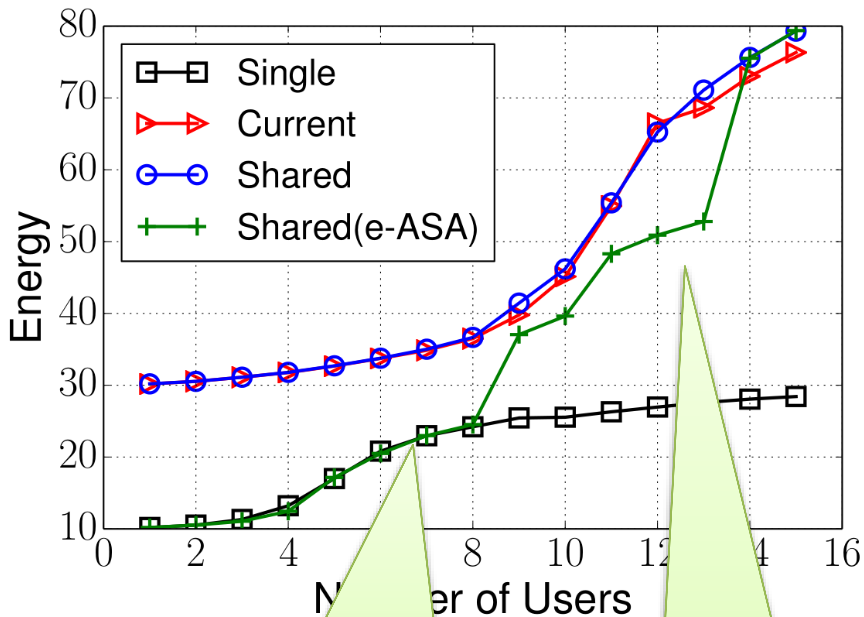
Proposed: Energy Aware Scheduling Algorithm and Queue Management (e-ASA)

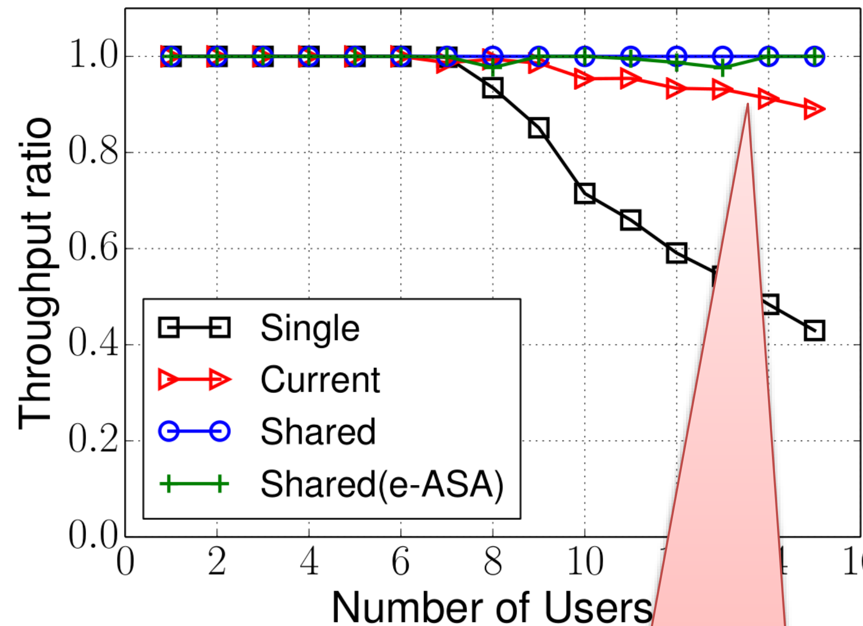
- Follows sleep and wake-up procedure of bands
- Depends on incoming traffic rates and QoS

e-ASA Based Multi-shared-band Scenario



Results-Energy and Throughput Ratio





Energy Consumption is lower

Energy consumption is increasing for heavy loads.

Throughput of proposed method is higher than current multi-band but a little lower than multi-shared-band.

Improvements: Multi-shared-band Router with e-ASA

Multi-shared-band with e-ASA

60%

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

Summary of Contributions in Wi-Fi

- **Multi-class traffic scheduling and queue management** for multi-band routers is proposed.
- **Energy aware scheduling and queue management** is developed for multi-band wireless router.
- Performances of the proposed methods are evaluated according to the queue systems and extensive simulations.

Research papers on multi-band in Wi-Fi

- [7] M. S. Hossain, **H. S. Narman**, and M. Atiquzzaman, ”A novel scheduling and queue management scheme for multi-band mobile routers,” IEEE International Conference on Communications (ICC), Budapest, Hungary, June 9-13, 2013, pp. 3787-3791.
- [8] **H. S. Narman**, M. S. Hossain, and M. Atiquzzaman, ”Multi class traffic analysis of single and multi-band queuing system,” IEEE Global Communications Conference (GLOBECOM), Atlanta, GA, Dec 9-13, 2013, pp. 1422 1427.
- [9] **H. S. Narman** and M. Atiquzzaman, ”Energy aware scheduling and queue management for next generation Wi-Fi routers,” IEEE Wireless Communications and Networking Conference Workshops (WCNCW), New Orleans, LA, Mar 9-12, 2015.
- [10] **H. S. Narman**, M. Hossain, and M. Atiquzzaman, ”Management and analysis of multi class traffic in single and multi-band systems,” Wireless Personal Communications, Feb 2015.

Conclusion

Extra Research Papers on Cloud Computing

- [11] **H. S. Narman**, Md. Shohrab Hossain and Mohammed Atiquzzaman: Scheduling Internet of Things Applications in Cloud Computing, (Submitted, Springer Annals of Telecommunication, 2016)

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

- [13] **H. 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://hsnarman.oucreate.com/

husnu@ou.edu