

QoS Aware Fuzzy Rule Based Vertical Handoff Decision Algorithm for Heterogeneous Wireless Networks

Sudipta Mahapatra, Ph. D

Associate Professor

Department of E & ECE

IIT Kharagpur

Sudipta@ece.iitkgp.ernet.in

Prof. C. S. Kumar

kumar@mech.iitkgp.ernet.in

Vasu K.

vasukanster@gmail.com

Sumit Maheswari

sumitece87@gmail.com

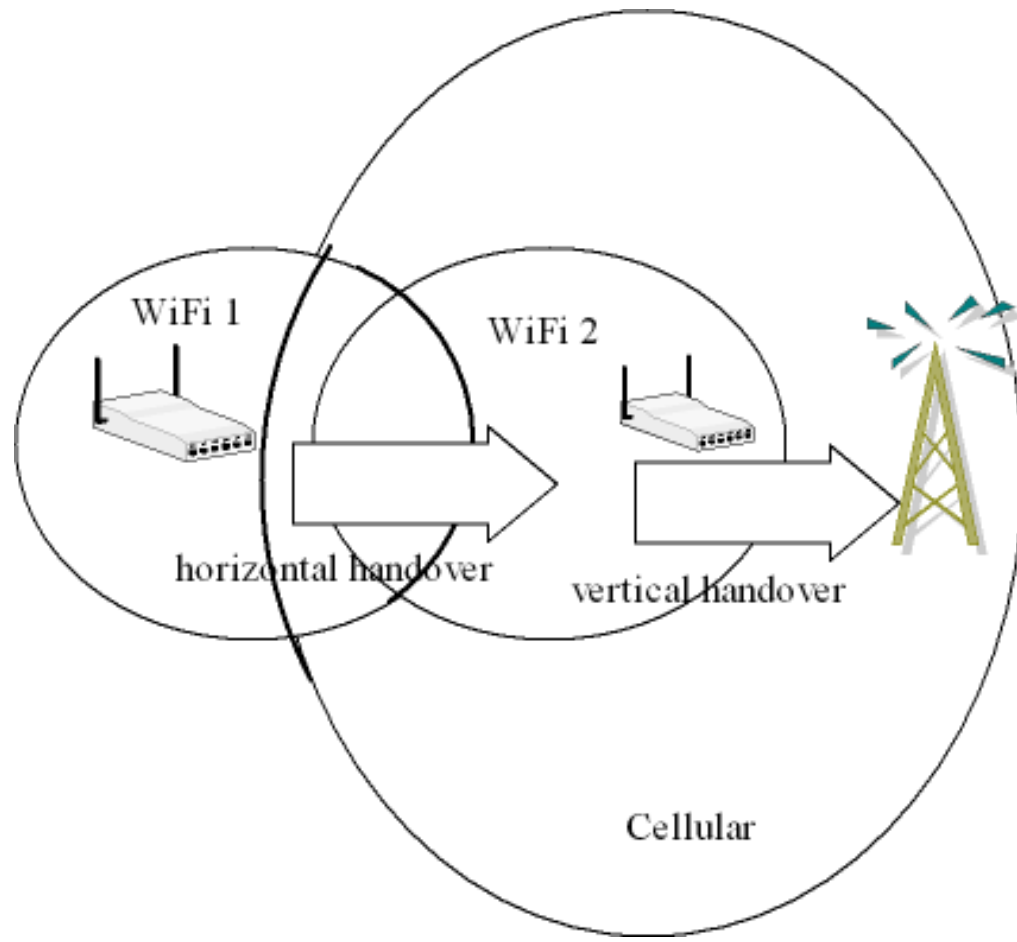
Outline

- Introduction – Vertical handoff
- Highlights of the work
- Fuzzy Rule Based System and Proposed Mechanism
- Evaluation model
- Simulation results
- Implementation in Mobile IP testbed
- Conclusion

Introduction

- Next Generation heterogeneous wireless networks require seamless mobility amongst the different access networks while maintaining QoS for various applications, such as high-speed data services, audio, video, and multimedia applications.
- In such networks it is necessary to employ efficient mobility management strategies to meet QoS requirements for different traffic classes while maintaining a fair utilization of wireless resources.
- Achieved with a good mechanism to handle handoff between two dissimilar networks, known as vertical handoff.

Horizontal and Vertical Handoff



Introduction (Contd.)

- Vertical handoff mechanisms involve three different phases of operations:
 - system discovery
 - handoff decision process
 - handoff execution.
- In system discovery phase, the system may periodically monitor the states of the networks to determine the network to which handoff can be carried out.
- The handoff decision process identifies the network to which handoff can be carried out.

Multi criteria-based decision

- Current literature indicates the advantage of a combination of some of the criteria like bandwidth, RSSI, and delay for making a handoff decision - especially in the presence of heterogeneous networks.
- The wide variation in the characteristics of the networks involved motivates one to explore the field of *fuzzy logic* to develop a handoff strategy.

Highlights of the Work

- QoS aware fuzzy rule based vertical handoff decision algorithm.
- Multi-criteria of **bandwidth**, **delay**, **jitter** and **bit error rate** considered for different traffic classes.
- A New evaluation model using a non birth-death Markov chain for creating the simulation environment.
- Implementation of proposed scheme using Mobile IP testbed at IISc.

IMT2000 QoS Classes and Requirements (3GPP-TS 23.107)

Traffic Class	BER	E2E Delay	Jitter	Bandwidth
Conversational	Need not be Low	Should be Low	Should be Low	Need not be High
Streaming	Need not be Low	Should be Low or Medium	Should be Low	Should be high
Interactive	Should be Low	Should be Medium or Low	Need not be low	Need not be high
Background	Should be Low	Need not be low	Need not be low	Should be Medium at least

Fuzzy Rule Based System (FRBS)

- Propositional logic - events are symbolized with either 'True/False' values.
- In predicate logic, events are symbolized with values other than just true or false;
- The predicate IsTall
 - is probably false for someone who is 4' tall,
 - is probably true for someone who is 7' tall,
 - is somewhere in between for someone at 5 1/2'.

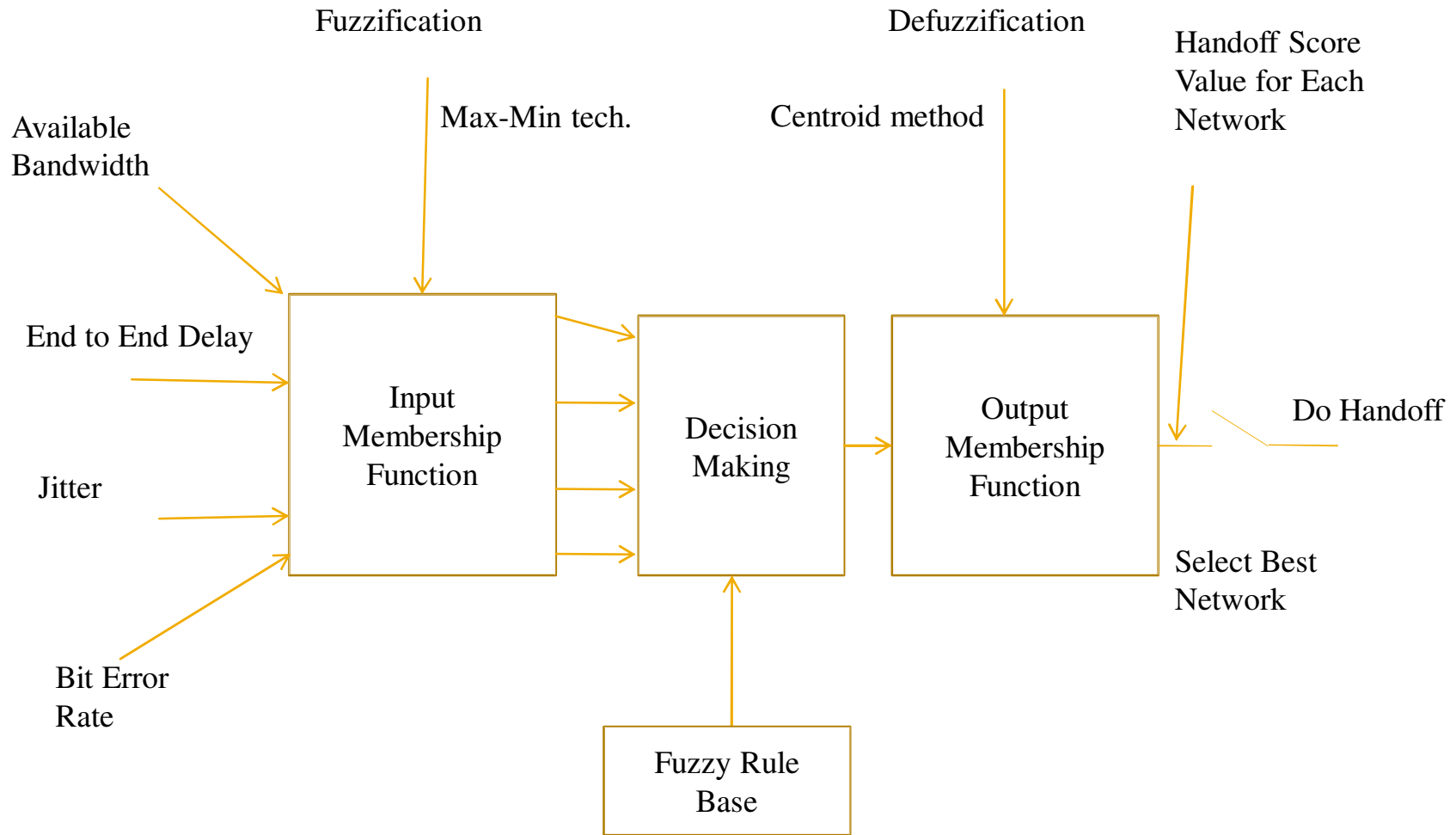
FRBS (Contd.)

- Associated with this linguistic variable is a set membership function that can take on values in the interval $[0, 1]$, rather than just from the set $\{0, 1\}$.
- A fuzzy set is a set with such a set membership function.

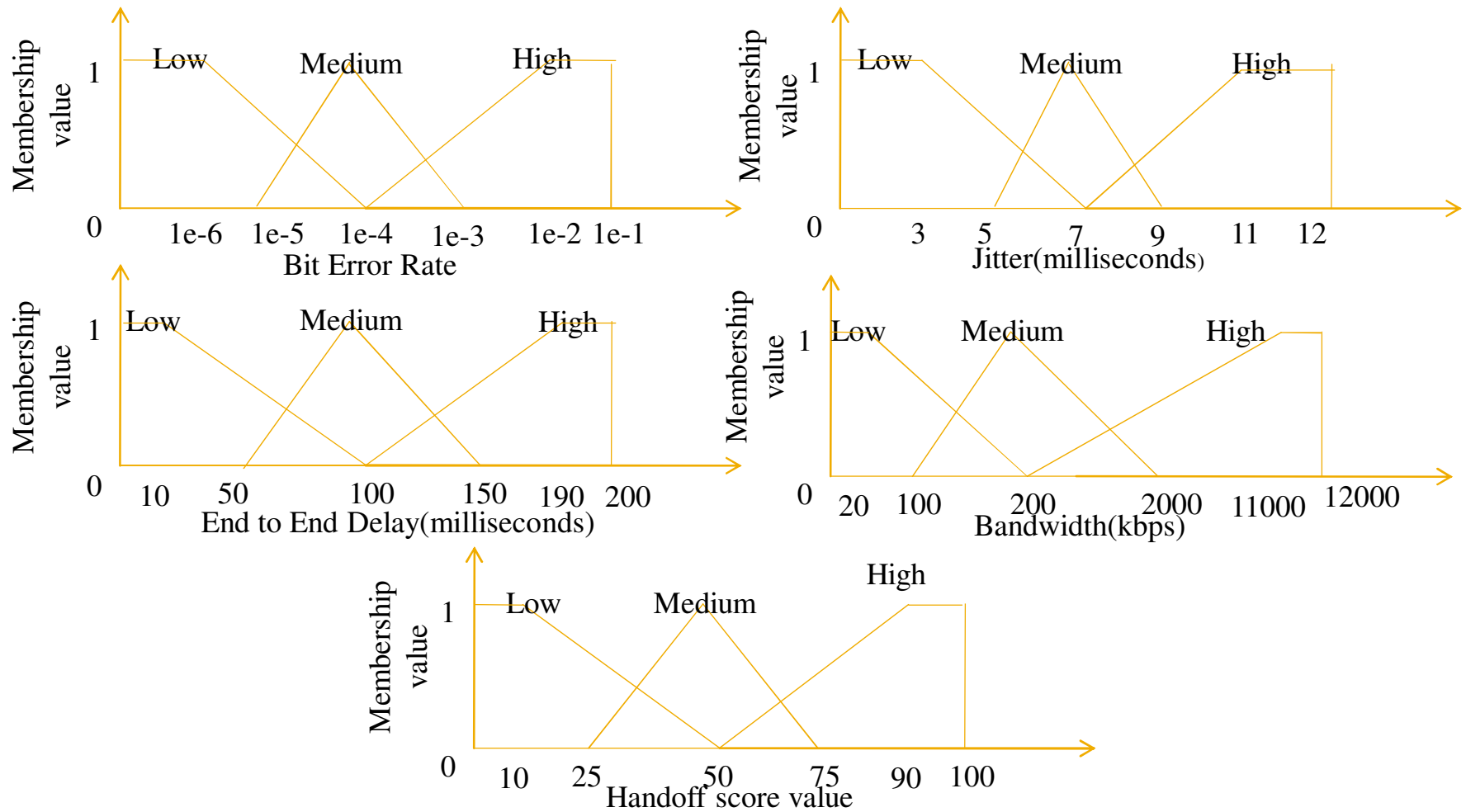
Fuzzyfication and defuzzyfication

- The process of taking a set of observations and creating a fuzzy set from it is called fuzzification.
- The inverse process is known as defuzzification.

The Proposed Mechanism



Fuzzy membership functions



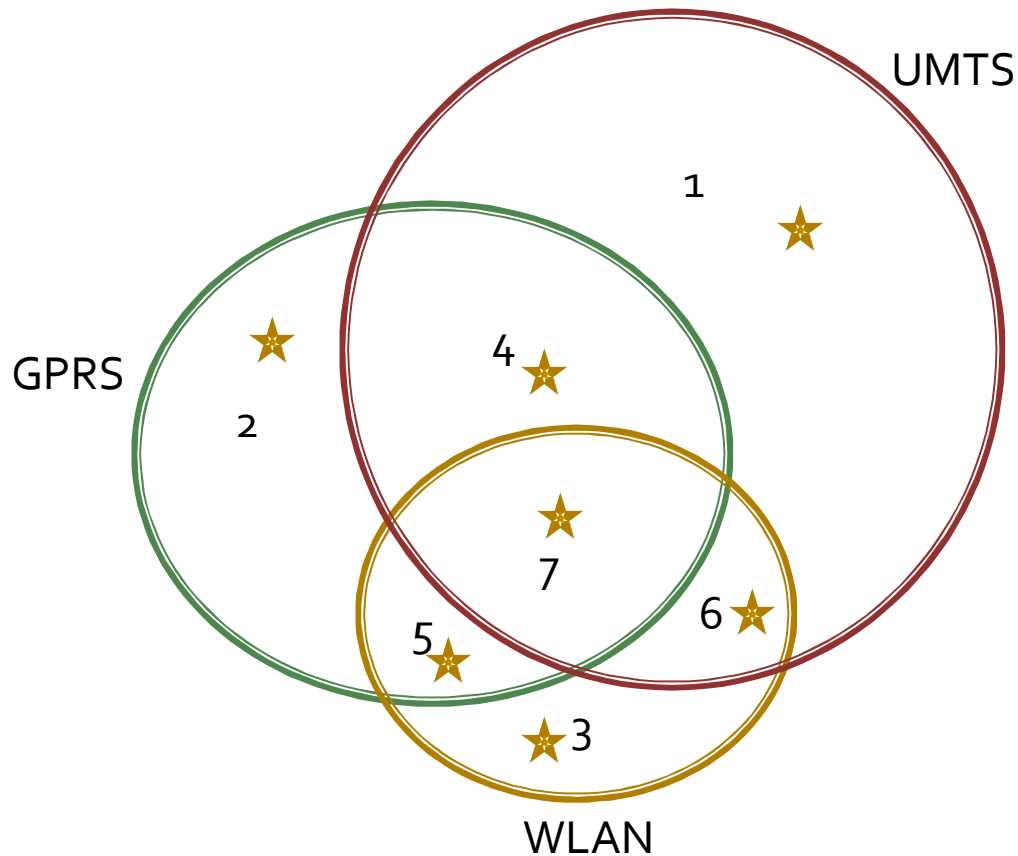
Sample rule base

Conversational					
Rule No	BER	E2E delay	Jitter	Bandwidth	Handoff score
1	low	low	low	low	high
25	low	high	high	low	low
50	medium	high	medium	medium	low
81	high	high	high	high	low
Streaming					
Rule No	BER	E2E delay	Jitter	Bandwidth	Handoff score
1	low	low	low	low	low
25	low	high	high	low	low
50	medium	high	medium	medium	high
81	high	high	high	high	medium

Sample rule base (Contd.)

Interactive					
Rule No	BER	E2E delay	Jitter	Bandwidth	Handoff score
1	low	low	low	low	medium
25	low	high	high	low	low
50	medium	high	medium	medium	low
81	high	high	high	high	low
Background					
Rule No	BER	E2E delay	Jitter	Bandwidth	Handoff score
1	low	low	low	low	medium
25	low	high	high	low	medium
50	medium	high	medium	medium	medium
81	high	high	high	high	medium

Wireless Heterogeneous Environment



☆ Mobile node position

0-7 State number

0 ----- No Network

1 ----- { UMTS }

2 ----- { GPRS }

3 ----- { WLAN }

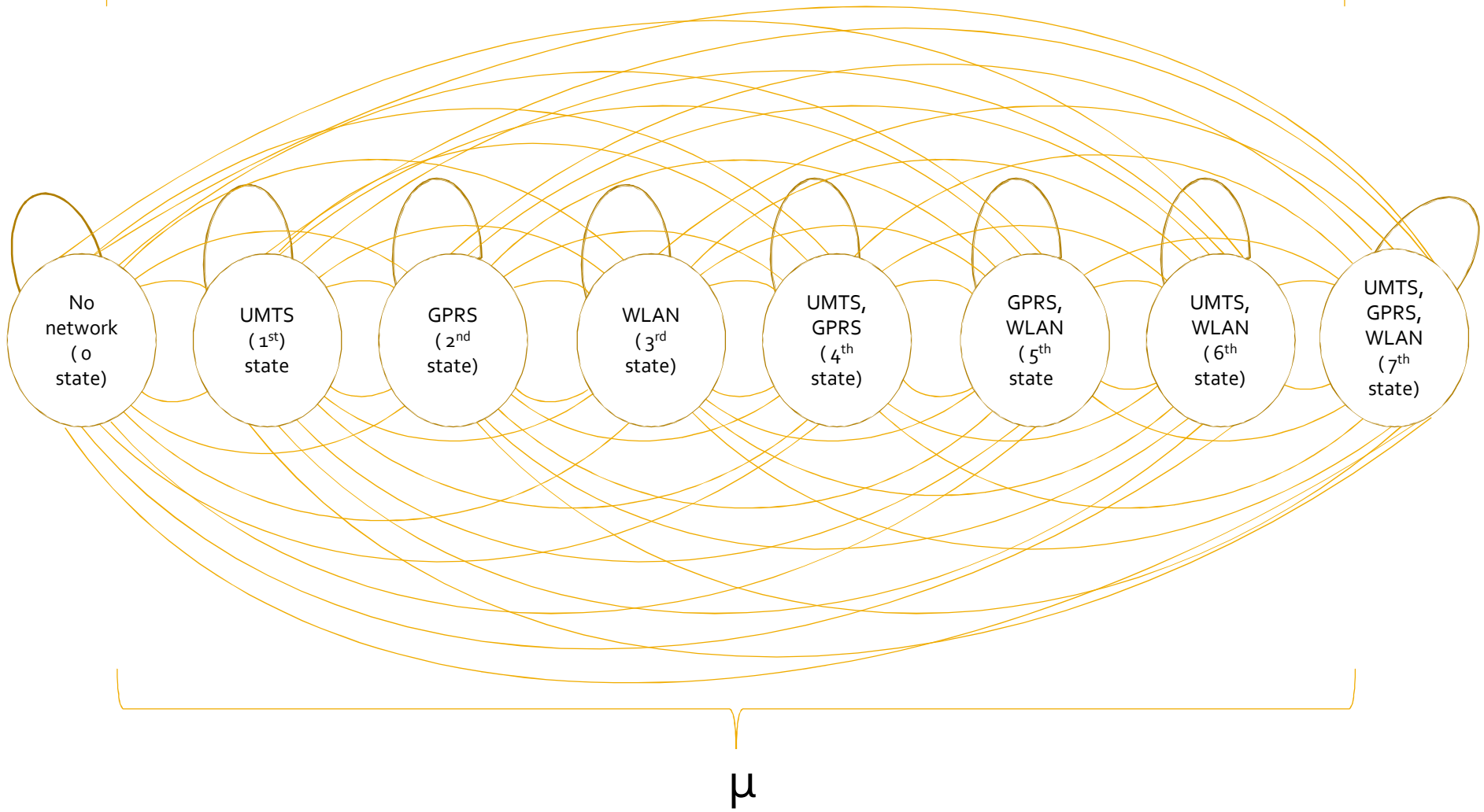
4 ----- { UMTS, GPRS }

5 ----- { GPRS, WLAN }

6 ----- { UMTS, WLAN }

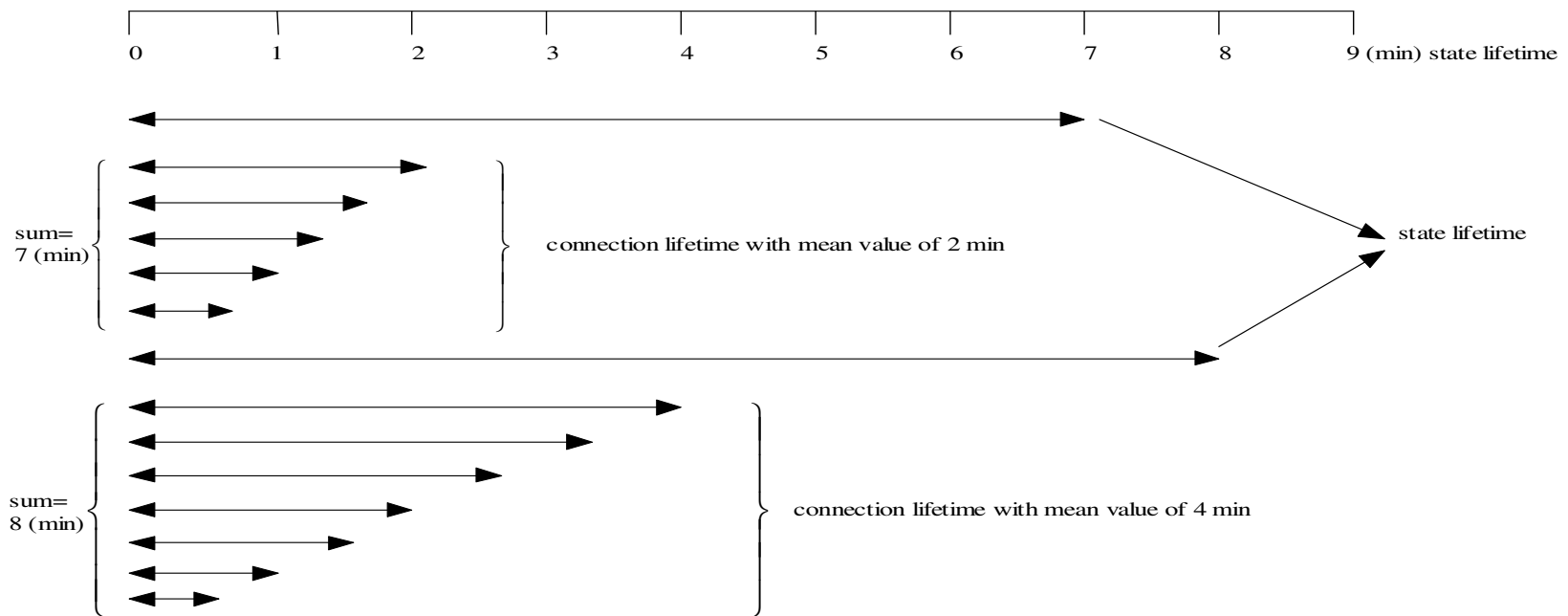
7 ----- { UMTS, GPRS, WLAN }

The Non Birth-death Markov Chain



Markov chain

State Lifetime and Connection Lifetime



Simulation Study: Assumptions

1. State transition time (or state lifetime) at state i is assumed to follow an exponential distribution with a mean λ_i .
2. State transitions are instantaneous and do not incur any waiting delays.
3. Within a state, connection lifetimes follow an exponential distribution with a mean μ .

Parameter vectors

- *Bandwidth vector:*
UMTS - [32, 64, 128, 256, 512, 1024, 2048] kbps
GPRS - [21, 42, 64, 85, 107, 128, 149, 171] kbps
WLAN- [1000, 2000, 5500, 11000] kbps
- *E-E Delay:*
UMTS– [190, 160, 130, 100, 70, 40, 10]msec
GPRS– [160, 110, 60, 10]msec
WLAN– [160, 110, 60, 10]msec
- *Jitter:*
[3, 5, 7, 9, 11] msec
- *Bit-error rate:*
[0.01, 0.001, 0.0001, 0.00001, 0.000001]

Ref. - Stevens-Navarro E. and Wong V. W. S., "Comparison between Vertical Handoff Decision Algorithms for Heterogeneous Wireless Networks", IEEE VTC, vol 2, pages: 947-951, 2006.

Evaluation Metrics

1. End-to-end delay
2. Available bandwidth
3. Jitter
4. Availability - $1 - \Pr[\text{the mobile is in state } 0]$.

Comparative study

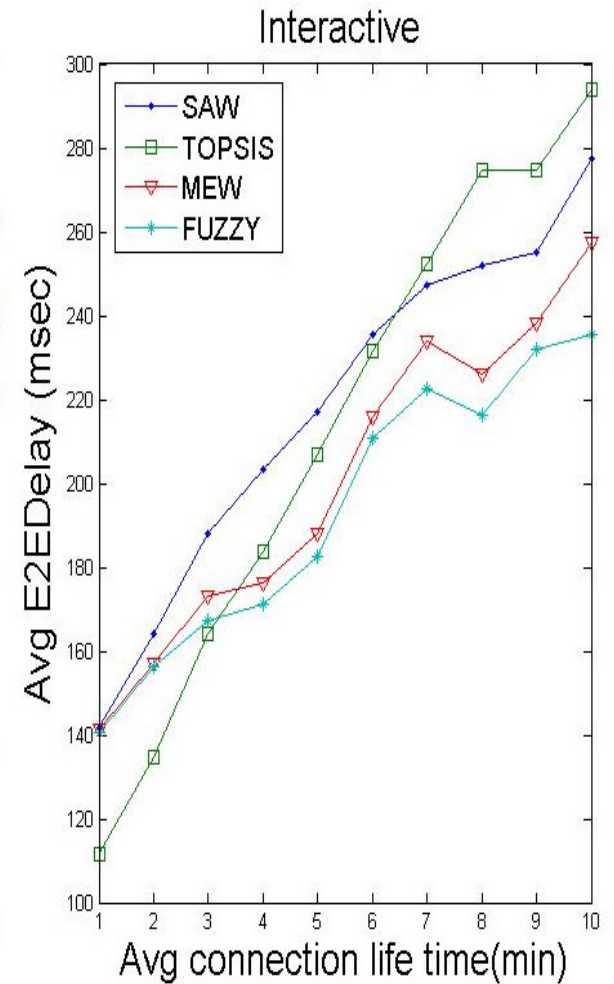
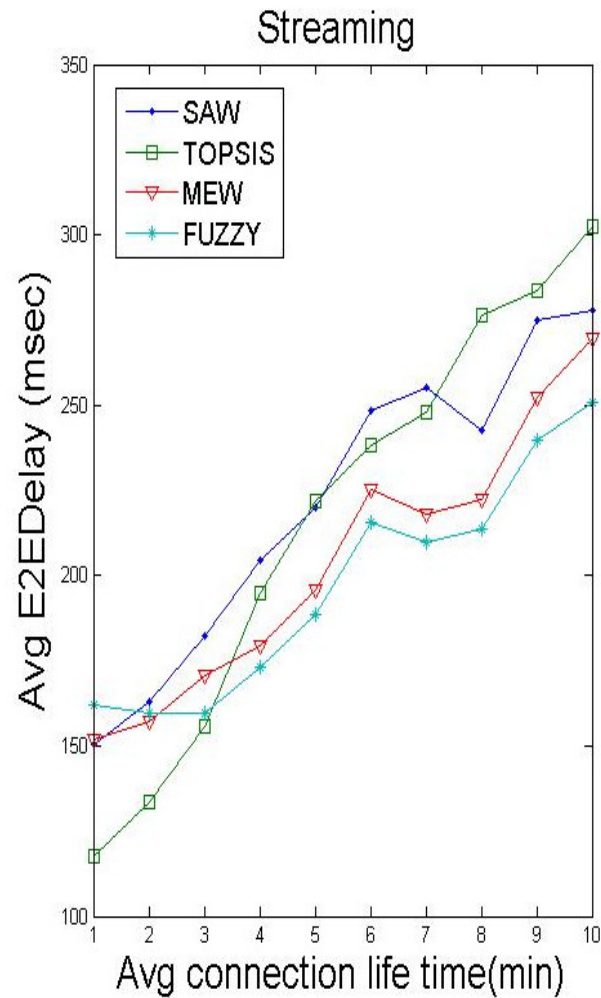
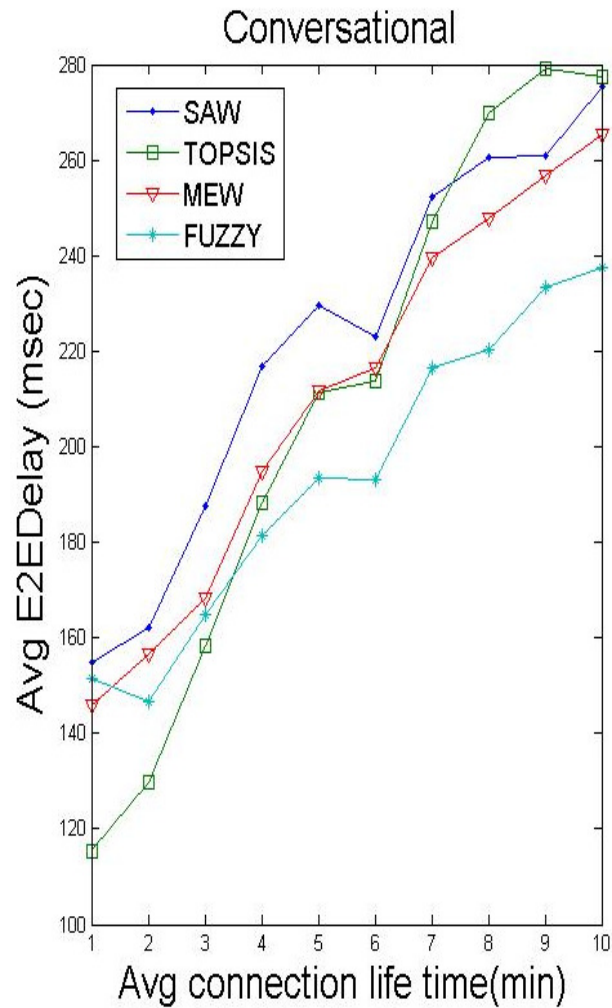
1. SAW (Simple additive weight).
2. TOPSIS (Techniques for order preference by similarity to ideal solution).
3. MEW (Multiplicative exponent weighting).

Importance weights - AHP

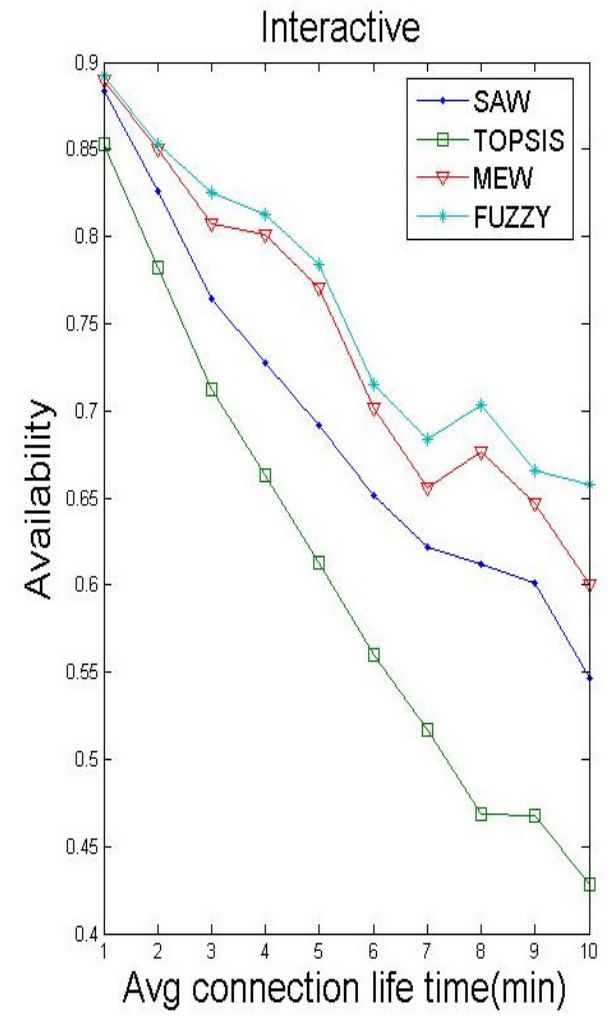
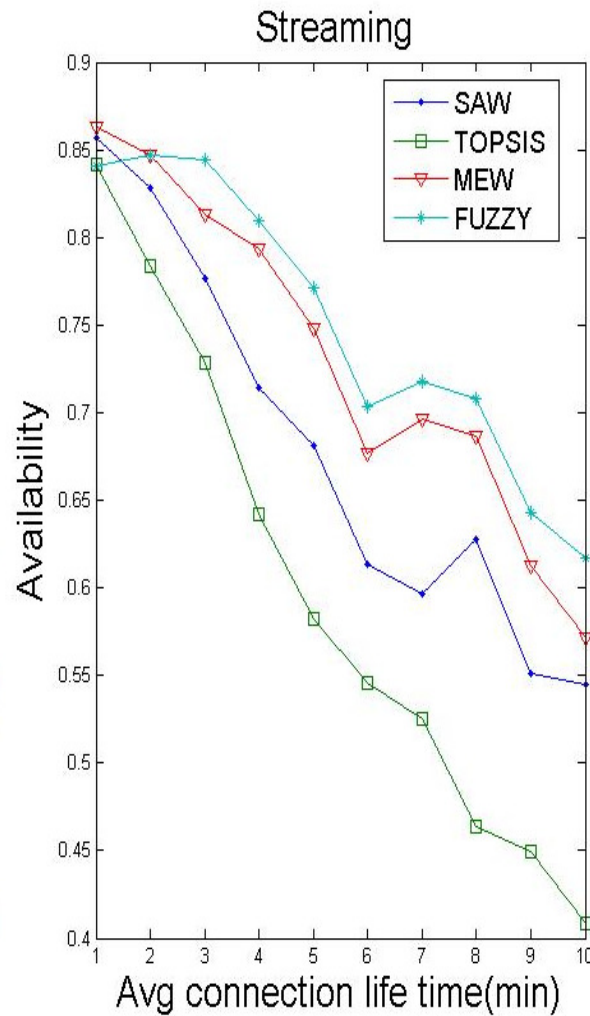
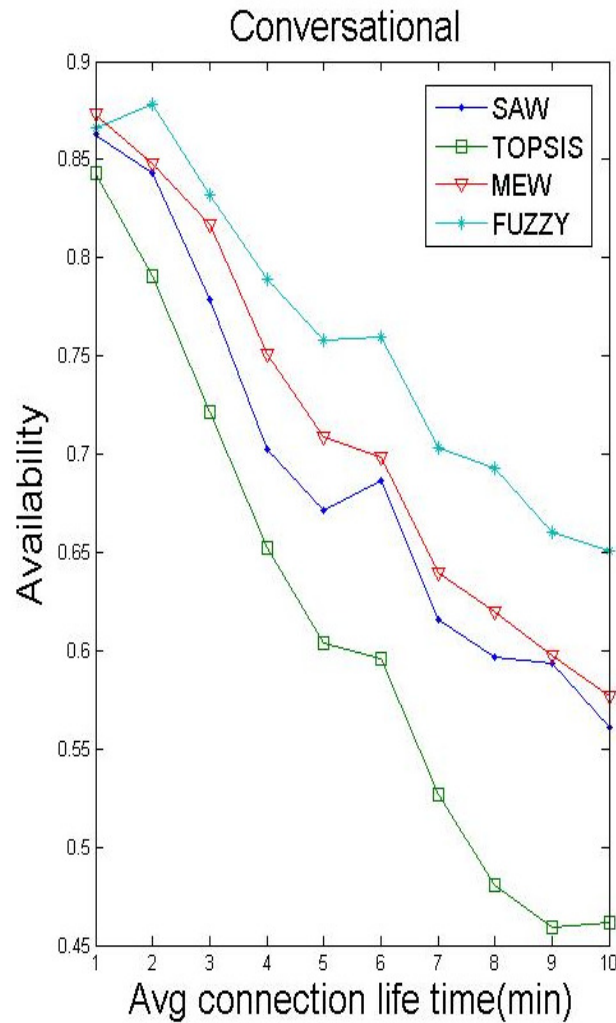
Traffic Class	BER	E2EDelay	Jitter	Bandwidth
Conversational	0.04998	0.45002	0.45002	0.04998
Streaming	0.03737	0.11380	0.42441	0.42441
Interactive	0.63593	0.16051	0.04304	0.16051
Background	0.66932	0.05546	0.05546	0.21976

Ref. - Stevens-Navarro E. and Wong V. W. S., "Comparison between Vertical Handoff Decision Algorithms for Heterogeneous Wireless Networks", IEEE VTC, vol. 2, pages: 947-951, 2006.

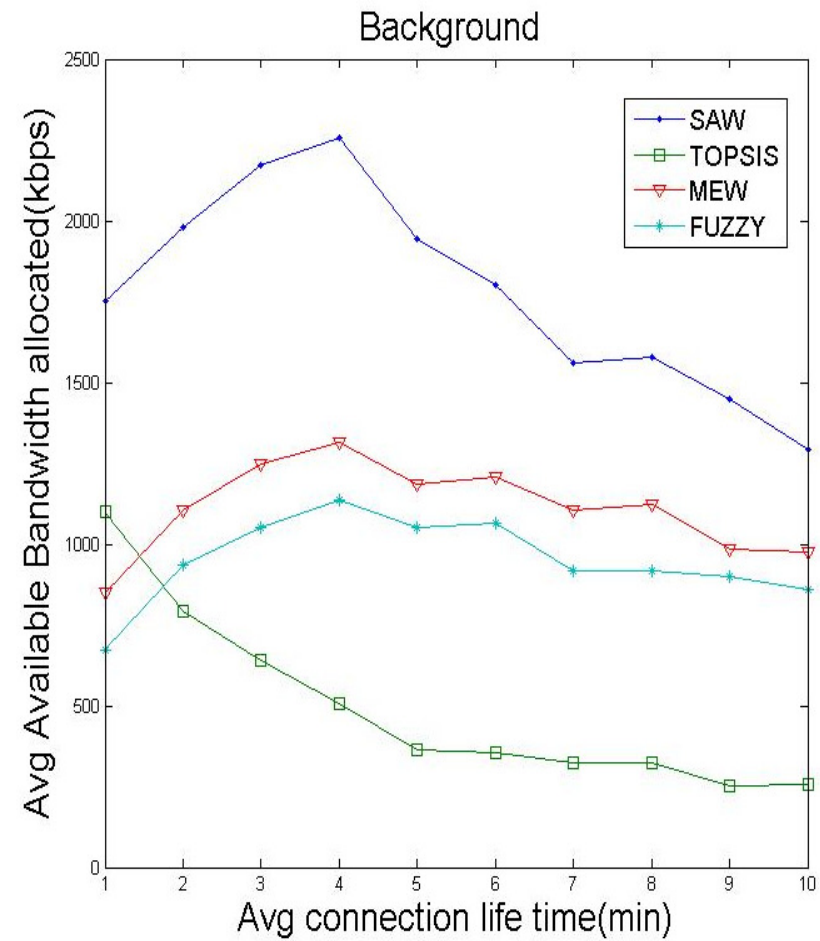
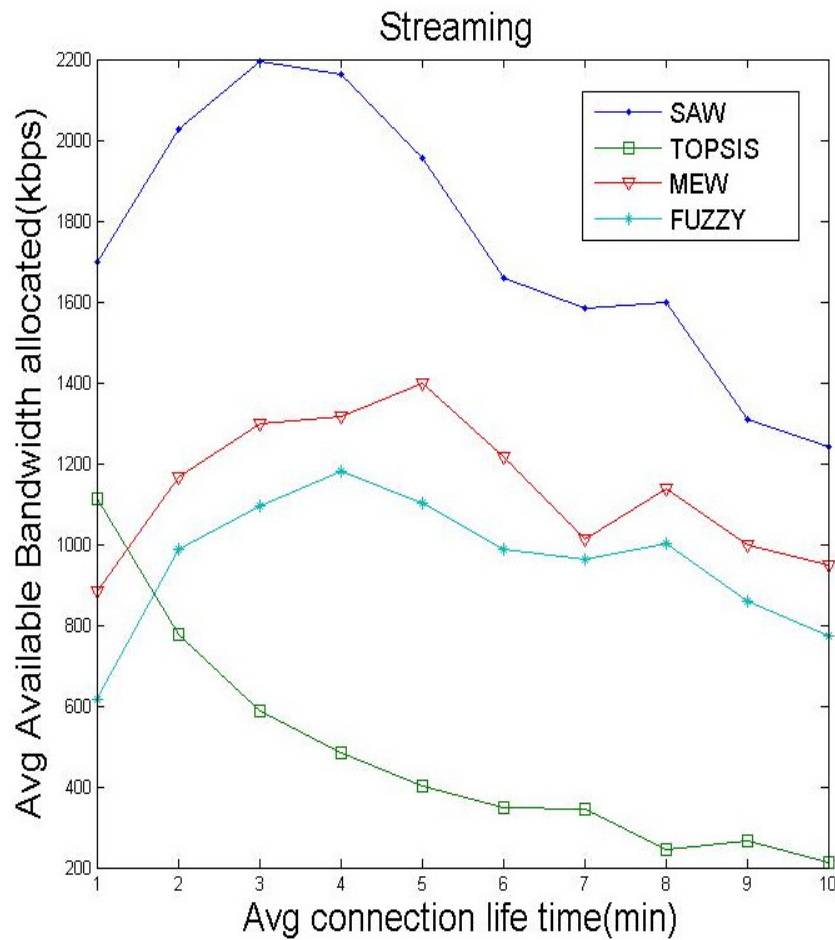
Results -Avg E2E Delay



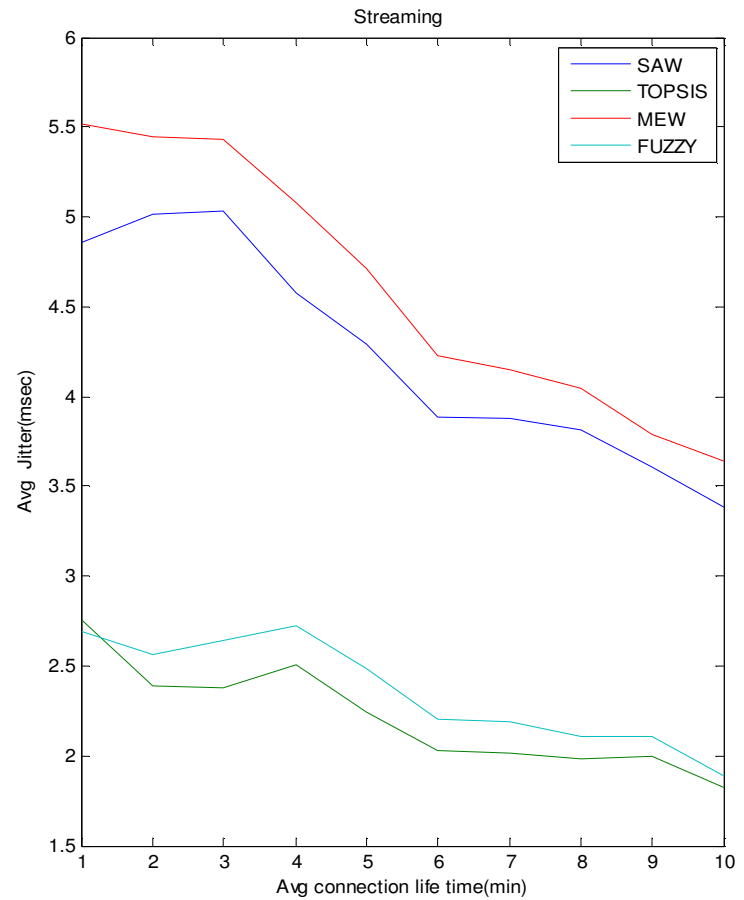
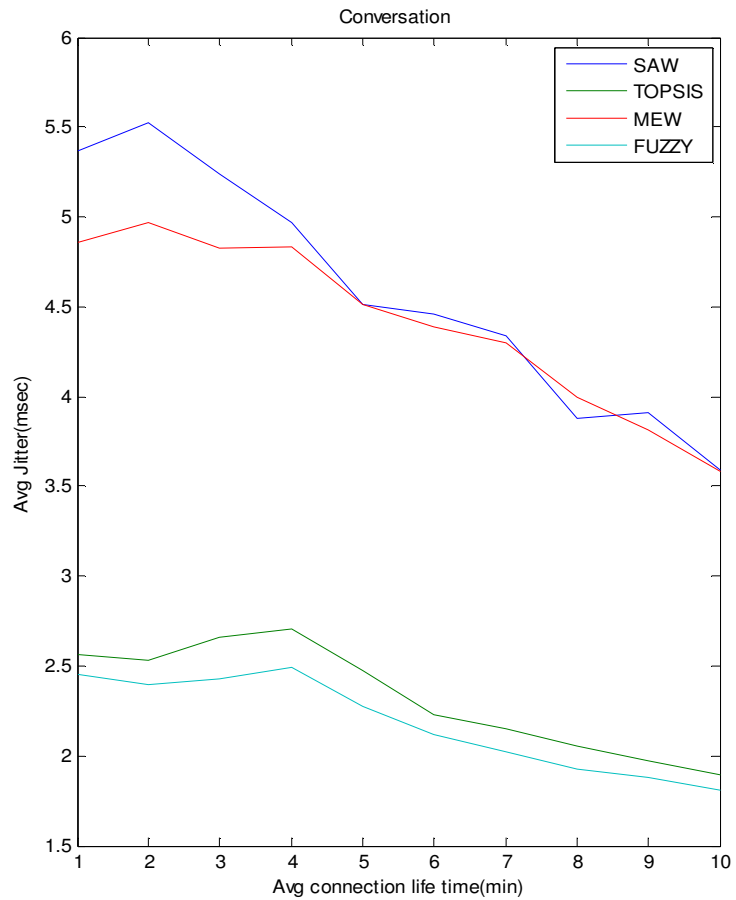
Results -Availability



Results -Avg Available BW

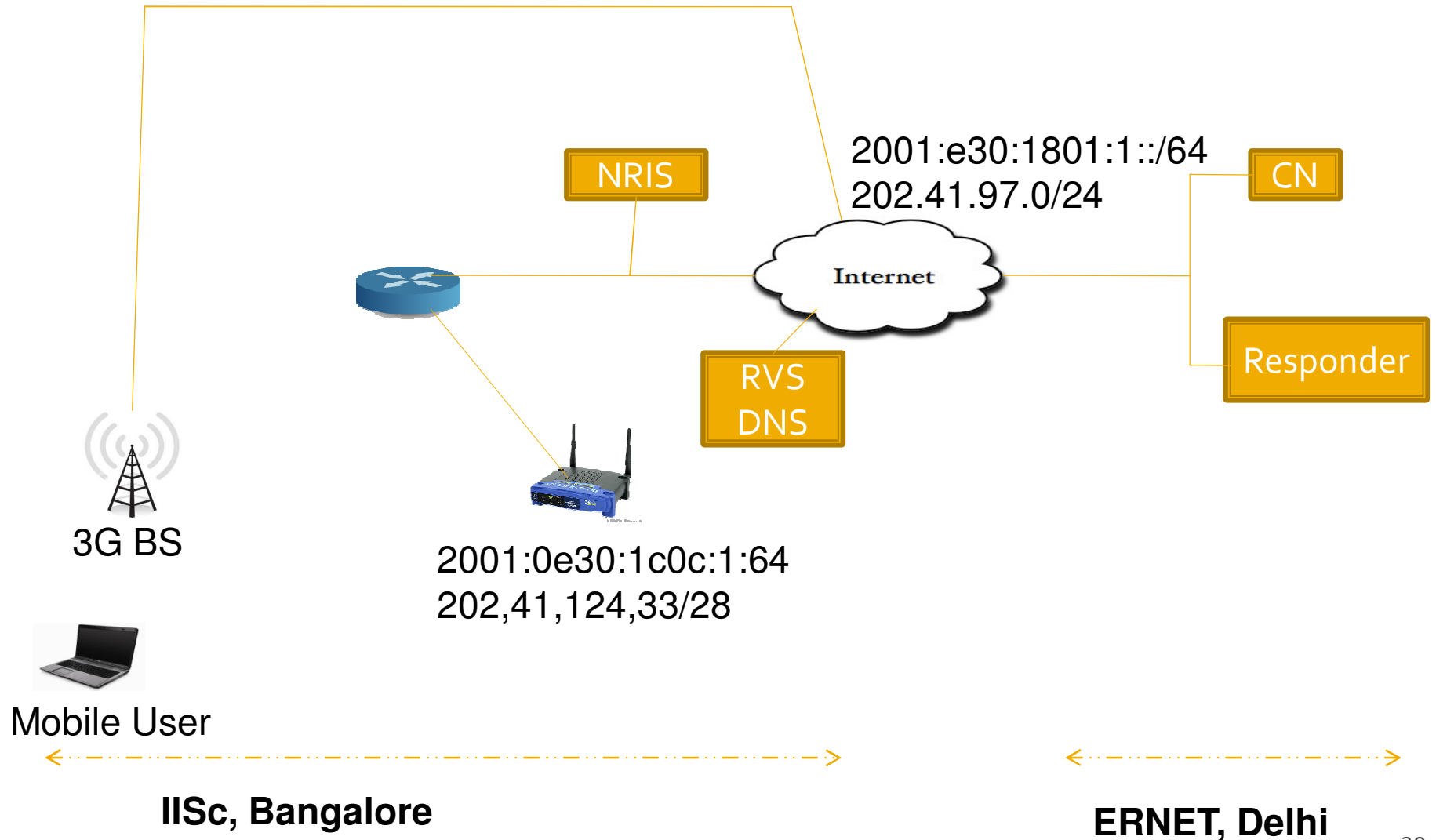


Results -Jitter

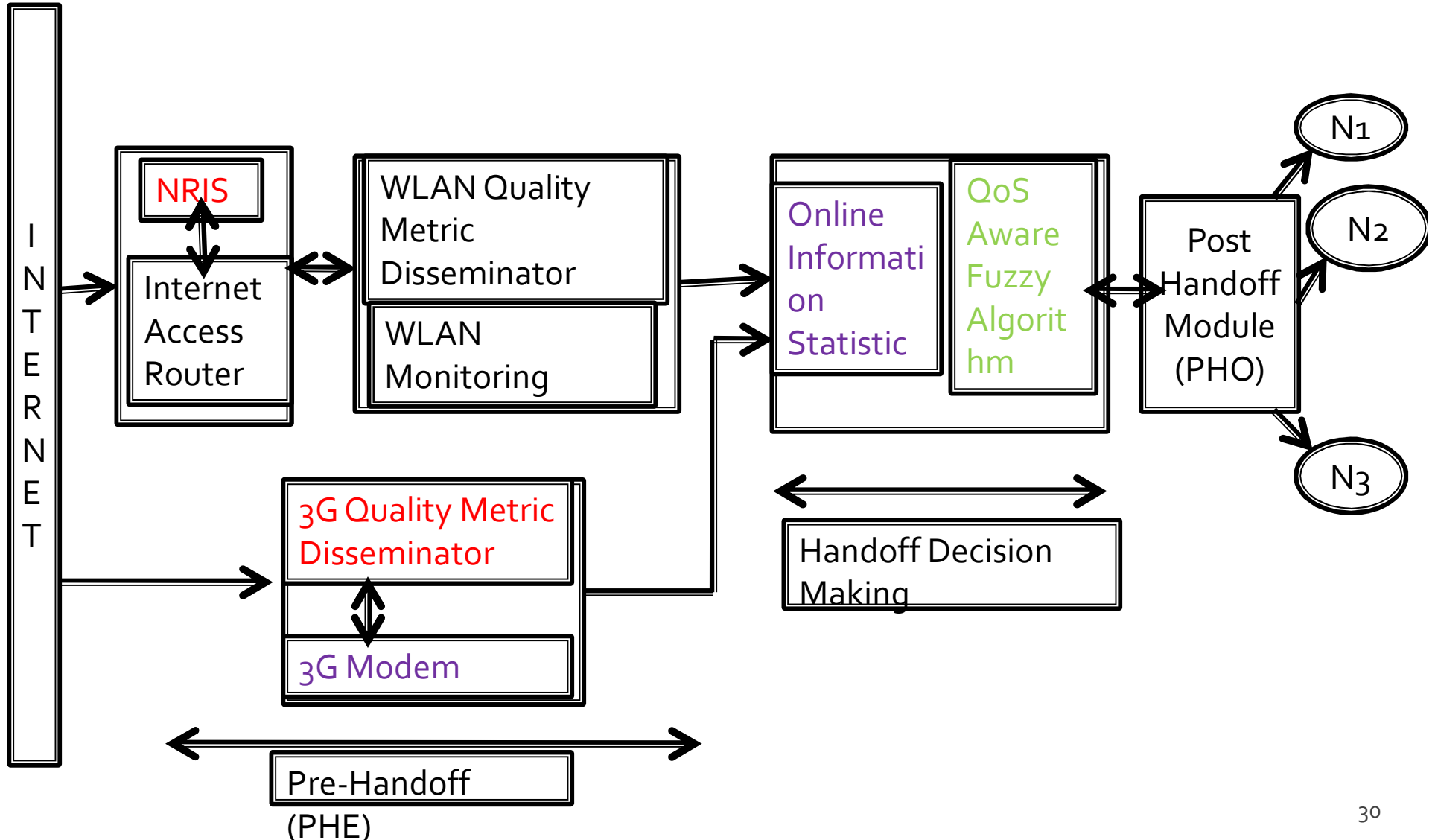


**Implementation of QoS Aware FRB
Vertical Handover using
Mobile IPv6 testbed at
IISc, Bangalore**

MobileIPv6 testbed



Software architecture



3G to WiFi-Before Handoff

The screenshot displays a Linux desktop environment with several windows open. The top panel shows system information: 33 °C, Sat Apr 16, 6:26 PM, and the user 'root'. A red circle highlights the network status icons in the top right.

Three terminal windows are visible:

- Terminal 1 (Left):** Shows the output of a script named 'fuzzy_rule_algo'. It repeatedly prints 'Current network: Airtel 134554368' and 'Algorithm triggered'. It also displays 'Inside Wifi Param' and 'inside wifi avg queue' values, such as '0.000278 133.750000 9.960001 1'.
- Terminal 2 (Top Right):** Shows the output of a script named 'pre_handoff'. It displays server information and signal strength, including 'SERVER: HOME, 7, -24.000000, 100.000000 1353.000000' and 'SERVER: Airtel, -83.239998, 0'.
- Terminal 3 (Bottom Left):** Shows a table of numerical data, likely representing network metrics over time. The values are: 0.000278, 133.750000, 9.960001, 1356.750000; 0.002500, 38.250000, 2.390000, 322.500000; 24.999998, 51.258320, 0.002528, 131.250000, 9.800001, 1355.250000; 0.000002, 37.500000, 2.350000, 357.500000; 25.000000, 50.775143; 0.002530, 128.750000, 9.640001, 1354.250000; 0.000025, 36.750000, 2.310000, 392.500000; 25.000000, 51.374443. A yellow circle highlights the last two rows of this table.

A VLC media player window is open in the foreground, displaying a scene from the animated movie 'Ice Age: The Meltdown'. The video shows a mammoth and a sloth in a snowy environment. The VLC interface includes playback controls, a volume slider set to 180%, and the URL 'rtp://[::]:5004'.

The taskbar at the bottom shows several open terminal windows and a 'Take ...' button.

3G to WiFi-During Handoff

The screenshot displays a Linux desktop environment with several windows open. The top panel shows system information: 33 °C, Sat Apr 16, 6:27 PM, and the user 'root'. A red circle highlights the network status icons in the top right.

Three terminal windows are visible:

- Terminal 1 (Left):** Shows the execution of a script. It reports the current network as 'Airtel 134554368', the algorithm triggered, and 'Inside Wifi Param' with an average queue of 0.002550. It then reports the current network as 'Airtel 134554368' again, followed by another 'Algorithm triggered' and 'Inside Wifi Param' with an average queue of 0.002550. The script ends with 'old_dev = 3, new_dev = 2'. A yellow circle highlights the text 'HANDING OFF TO HOME' and the active connection path.
- Terminal 2 (Top Right):** Shows the output of a script for the 'pre_handoff' phase. It displays 'from nris server' with values 1350.000000, 87.500000, and 7.000000. It then shows 'SERVER: HOME, 7, -24.000000, 100.000000 1350.000000' and 'SERVER: Airtel, -89.440002, 0'. This is followed by another 'from nris server' with values 1348.000000, 85.000000, and 6.840000, and 'SERVER: HOME, 7, -22.000000, 100.000000 1348.000000' and 'SERVER: Airtel, -89.440002, 0'.
- Terminal 3 (Bottom Left):** Shows a table of data points. A yellow circle highlights the last two rows of the table.

The VLC media player window (bottom right) is playing a video of a bear's face underwater. The status bar at the bottom shows the URL 'rtp://[::]:5004', a 1.00x playback speed, and a 00:00/00:00 duration.

Time	Value 1	Value 2	Value 3
0.002800	91.250000	7.240004	1350.000000
0.000000	25.500000	1.710001	917.500000
48.714657	53.331951		
0.002550	88.750000	7.080004	1349.750000
0.000025	24.750000	1.670001	952.500000
55.042702	54.832218		
0.002550	86.250000	6.920004	1349.000000
0.000250	24.000000	1.630001	987.500000
59.495281	54.248436		

3G to WiFi-After Handoff

The screenshot displays a Linux desktop environment with the following components:

- Terminal Window 1 (Left):** `root@localhost:~/Desktop/mmh-kgp/fuzzy_rule_algo`. It shows the execution of a script with the following output:

```
Inside Wifi Param
inside wifi avg queue: 0.003025 61.250000      5.320005      1
334.000000
Current network: HOME 7
Inside Observe Wifi
Algorithm triggered
Inside Wifi Param
inside wifi avg queue: 0.002777 58.750000      5.160006      1
332.500000
Current network: HOME 7
Inside Observe Wifi
Algorithm triggered
Inside Wifi Param
inside wifi avg queue: 0.000280 56.250000      5.000006      1
332.000000
Current network: HOME 7
Inside Observe Wifi
Algorithm triggered
Inside Wifi Param
```
- Terminal Window 2 (Right):** `root@localhost:~/Desktop/mmh-kgp/pre_handoff`. It shows the execution of a script with the following output:

```
6      0.001000
SERVER: HOME, 7, -20.000000, 100.000000 1331.000000
SERVER: Airtel, -91.300003, 0
SERVER: Airtel, -91.300003, 0
from nris server: 1331.000000      55.000000      4.92000
6      0.000010
SERVER: HOME, 7, -20.000000, 100.000000 1331.000000
SERVER: Airtel, -91.300003, 0
from nris server: 1332.000000      52.500000      4.76000
6      0.000010
SERVER: HOME, 7, -20.000000, 100.000000 1332.000000
```
- Terminal Window 3 (Bottom Left):** `root@localhost:~/Desktop/mmh-kgp/fuzzy_r`. It displays a table of numerical data:

0.003025	61.250000	5.320005	1334.000000
0.000025	15.000000	1.150002	1407.500000
58.760235	58.326244		
0.002777	58.750000	5.160006	1332.500000
0.002500	14.250000	1.110001	1442.500000
59.850967	58.500248		
0.000280	56.250000	5.000006	1332.000000
0.000250	13.500000	1.070001	1477.500000
58.555038	58.169525		
- VLC media player (Bottom Right):** `rtp://[::]:5004 - VLC media player`. It is playing a video showing a dog's face. The interface includes playback controls and a volume indicator set to 180%.

WiFi to 3g-Before Handoff

The screenshot displays a Linux desktop environment with several windows open. The top panel shows system information: 31 °C, Sat Apr 16, 7:03 PM, and the user 'root'. A red circle highlights the network status icons in the top right corner.

Three terminal windows are visible:

- Terminal 1 (top left):** `root@localhost:~/Desktop/mmh-kgp/fuzzy_rule_algo`. It shows the execution of `./fuzzy`, which outputs: "This is the client program inside wifi_data thread", "Inside Wifi Param", "Current network: HOME 7", "Inside Observe Wifi", "Inside Wifi Param", "Current network: HOME 7", "Inside Observe Wifi", "Inside Wifi Param", "Current network: HOME 7", "Inside Observe Wifi", "Inside Wifi Param".
- Terminal 2 (top right):** `root@localhost:~/Desktop/mmh-kgp/pre_handoff`. It shows the execution of `inside threeg thread function`, which outputs: "SERVER: Airtel, 0.000000, 0", "Received message from client : Hello 0", "SERVER: Airtel, -89.440002, 0", "from nris server: 1279.000000 150.000000 11.000000", "00 0.000000", "SERVER: HOME, 7, -23.000000, 100.000000 1279.000000", "SERVER: Airtel, -89.440002, 0", "from nris server: 1278.000000 147.500000 10.840000", "00 0.001000", "SERVER: HOME, 7, -23.000000, 100.000000 1278.000000".
- Terminal 3 (bottom left):** `root@localhost:~/Desktop/mmh-kgp/fuzzy_r`. It shows the execution of `./handoff`.

A VLC media player window is open in the bottom right, titled `tp://[::]:5004 - VLC media player`. It is playing a video of a mammoth and a small insect. The playback controls show a progress bar, play/pause, stop, previous, next, full screen, playlist, and equalizer buttons. The volume is set to 180% and the temperature is 34°C. The address bar shows `rtp://[::]:5004` and the playback time is `00:00/00:00` at `1.00x` speed.

WiFi to 3g-During Handoff

The screenshot displays a Linux desktop environment with several open windows. The top window is a terminal window titled "root@localhost:~/Desktop/mmh-kgp/fuzzy_rule_algo". It shows a sequence of commands and outputs related to network observation and handoff. A yellow oval highlights the following text:

```
HANDING OFF TO Airtel
Active connection path is - /org/freedesktop/NetworkManager/ActiveConnection/12
```

The middle window is another terminal window titled "root@localhost:~/Desktop/mmh-kgp/pre_handoff". It displays a table of network parameters:

from nris server:	1279.000000	150.000000	11.000000
00	0.000000		
SERVER: HOME, 7,	-23.000000,	100.000000	1279.000000
SERVER: Airtel,	-89.440002,	0	
from nris server:	1278.000000	147.500000	10.840000
00	0.001000		
SERVER: HOME, 7,	-23.000000,	100.000000	1278.000000
SERVER: Airtel,	-87.580002,	0	
from nris server:	1275.000000	145.000000	10.680000
00	0.000010		
SERVER: HOME, 7,	-20.000000,	100.000000	1275.000000

The bottom window is a terminal window titled "root@localhost:~/Desktop/mmh-kgp/fuzzy_r". It shows the execution of a script named "handoff":

```
[root@localhost fuzzy_rule_algo]# ./handoff
0.000000 0.000000 0.000000 0.000000
0.000033 57.000000 3.506667 150.000000
25.000000 38.414700
```

A yellow oval highlights the second and third lines of output. The right side of the desktop shows a VLC media player window titled "tp://[::]:5004 - VLC media player". The video content shows a scene from the animated movie "The Wild Thornberrys Movie". The VLC interface includes playback controls, a volume slider set to 180%, and a progress bar at the bottom.

The system tray at the bottom of the desktop shows the date and time as "Sat Apr 16, 7:03 PM" and the temperature as "31 °C". The user is logged in as "root".

WiFi to 3g-After Handoff

The screenshot displays a Linux desktop with several open windows. The top bar shows system information: 31 °C, Sat Apr 16, 7:03 PM, and the user 'root'. A red circle highlights the network status icons in the top right.

Three terminal windows are visible:

- Terminal 1 (Left):** Shows the execution of a script. The output includes:

```
old_dev = 2, new_dev = 3
HANDLING OFF TO Airtel
Active connection path is - /org/freedesktop/NetworkManager/ActiveConnection/12
HANDOFF DELAY = 3:484934
Message has no arguments!
Inside Wifi Param
inside wifi avg queue: 0.000505 146.250000 10.760000 1276.500000
Current network: Airtel 7
Algorithm triggered
Inside Wifi Param
inside wifi avg queue: 0.000370 145.000000 10.680000 1276.000000
Current network: Airtel 7
Algorithm triggered
Inside Wifi Param
```
- Terminal 2 (Right):** Shows network statistics for 'pre_handoff'. The output includes:

```
00 0.000100
SERVER: HOME, 7, -23.000000, 100.000000 1275.000000
SERVER: Airtel, -89.440002, 0
from nris server: 1274.000000 140.000000 10.3600
01 0.000001
SERVER: HOME, 7, -23.000000, 100.000000 1274.000000
SERVER: Airtel, -87.580002, 0
from nris server: 1274.000000 137.500000 10.2000
01 0.001000
SERVER: HOME, 7, -19.000000, 100.000000 1274.000000
SERVER: Airtel, -87.580002, 0
```
- Terminal 3 (Bottom Left):** Shows a table of network statistics. The data is as follows:

0.000000	0.000000	0.000000	0.000000
0.000033	57.000000	3.506667	150.000000
25.000000	38.414700		
0.000505	146.250000	10.760000	1276.500000
0.000000	42.000000	2.590000	147.500000
24.999998	39.856701		
0.000370	145.000000	10.680000	1276.000000
0.000250	41.250000	2.550000	182.500000
25.000004	45.331486		

A VLC media player window is open in the foreground, showing a video of a brown, furry creature. The VLC interface includes playback controls and a volume indicator set to 180%.

Issues addressed and observations

- Focused on a QoS aware fuzzy rule based algorithm that makes a multi-criteria based decision considering the *available bandwidth, end-to-end delay, jitter* and *bit error rate* of the networks, for a variety of traffic classes.
- Obtaining the QoS Parameters for applications before making the connection to a new network.
- Handoff delay from 3G to WiFi is 6sec and from WiFi to 3G is 3sec observed.
- Running Mobile IP protocols at both client side and server side.

Acknowledgment

- This work was carried out under the Vodafone Essar sponsored research project at IIT Kharagpur, India.
- We would like to thank the team of Mohammad Rafiq, Seema Kumar, Nagaraj Kammar, Guru Prasad, Gopi Krishna S Garge, Anand SVR, and Malati Hegde, Dept. of Electrical Communication Engg., Indian Institute of Science Bangalore for providing the mobile IP testbed and for the wonderful support received during the period.



QUESTIONS?





References

- [1] Ikram Smaoui, Faouzi Zarai and Lotfi Kamoun, "Vertical Handoff Management for Next Generation Heterogeneous Networks", in Proc. IEEE CCC, 2007.
- [2] Enrique Stevens-Navarro and Vincent W.S. Wong, "Comparison between Vertical Handoff Decision Algorithms for Heterogeneous Wireless Networks", IEEE VTC, vol 2, pages: 947-951, 2006.
- [3] Xie Shengdong and Wu Meng, "Vertical Handoff Algorithm in Heterogeneous Networks for Reducing Interference", Journal of Electronics (China), Vol.26, No.1, January 2009.
- [4] Nirmala Shenoy and Sumita Mishra, "Vertical Handoff and Mobility Management for Seamless Integration of Heterogeneous Wireless Access Technologies", Heterogeneous Wireless Access Networks, Springer Science + Business Media, LLC 2008.



References

- [5] Anita Singhrova and Dr. Nupur Prakash, "A Review of Vertical Handoff Decision Algorithm in Heterogeneous Networks", in ACM, September, 2007.
- [6] Behrouz Shahgholi, Ghahfarokhi and Naser Movahhedinia, "A context-aware handover decision based on user perceived quality of service trigger", in Wirel. Commun. Mob. Comput, Wiley InterScience, 2009.
- [7] Kishor S.Trivedi, S. Dharmaraja and Xiaomin Ma, "Analytic modeling of handoffs in wireless cellular networks", in Information Sciences, Elsevier February, 2002.
- [8] Gowrishankar, G. N. Sekhar and P.S Satyanarayana, "Analytic Performability Model of Vertical Handoff in Wireless Networks", in Journal of Computer Science, ISSN, 2009.



References

- [9] Gunter Bolch, Stefan Greiner, Hermann de Meer and Kishor S. Trivedi, "Queuing Networks and Markov Chains", John Wiley and Sons, ISBN 0-471-20058-1
- [10] 3GPP, "IMT -2000 QoS classes", TSG-SA #17 Meeting September 2002.
- [11] 3GPP, "QoS concepts and architecture", TS 23.107 v9.0.0 (2009-12).
- [12] Asli Celikyilmaz and I. Burhan Turksen, "Modeling Uncertainty with Fuzzy Logic with Recent Theory and Applications" , Springer 2009, ISBN 978-3-540-89923-5.