Autonomic Management for Personalized Handover Decisions in Heterogeneous Wireless Networks

- PhD Thesis Defense -

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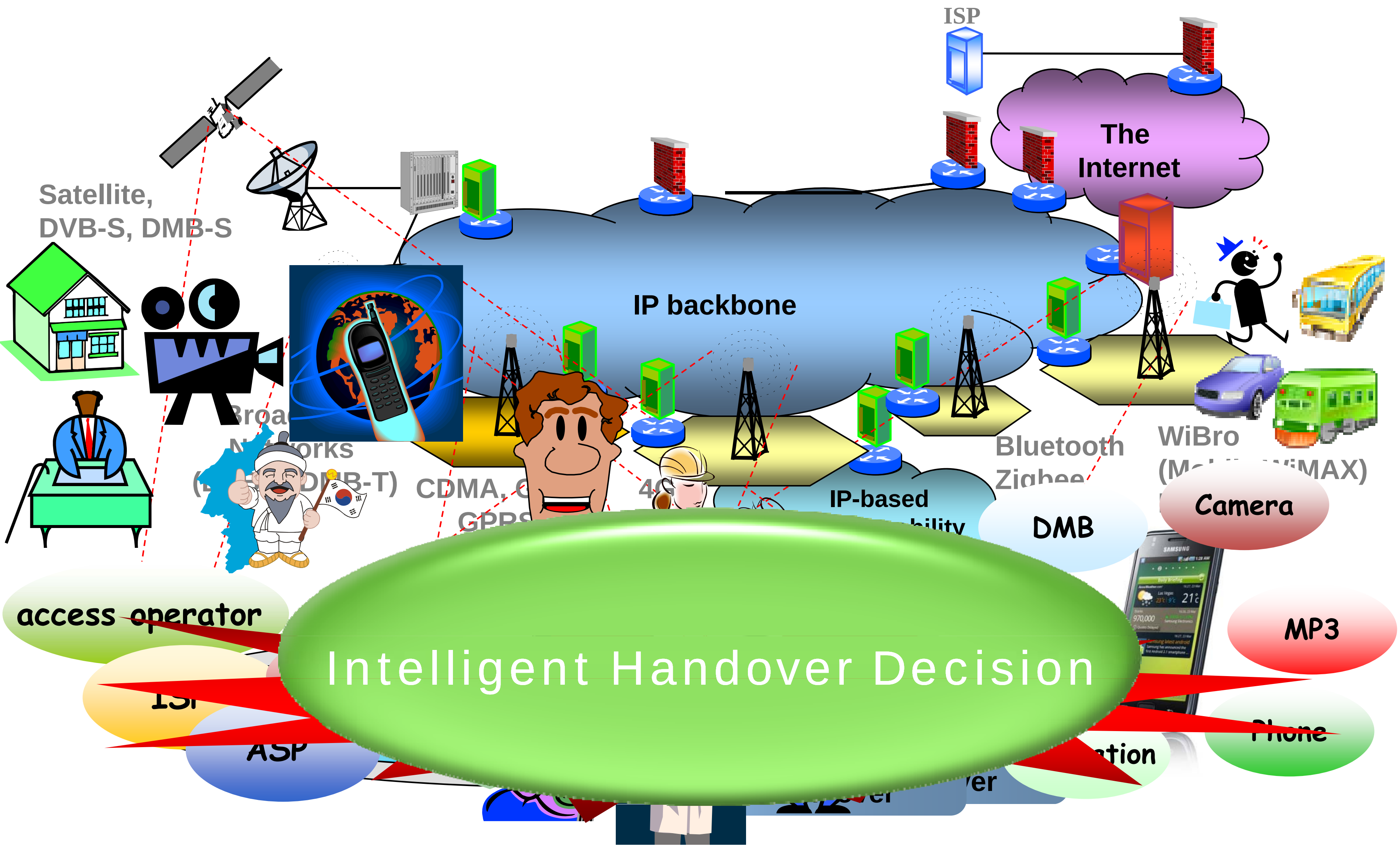
Presentation Outline

- Introduction
- Related Work
- Solution Approach
- Autonomic Personalized Handover Decision
- Development of HMNToolSuite
- Evaluation and Results
- Conclusions

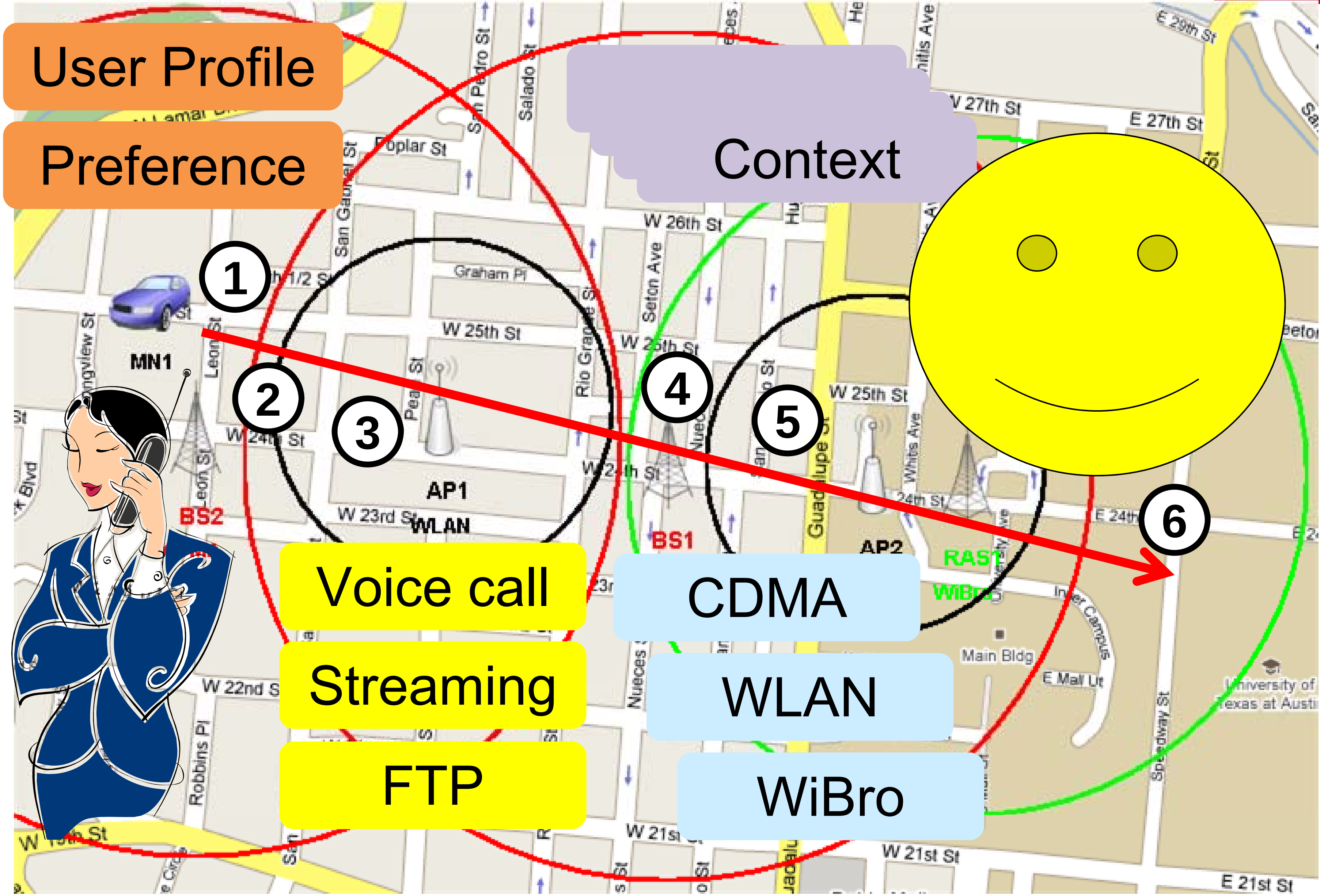
Introduction

1. Heterogeneous Wireless Networks
2. Research Motivation
3. Problem Definition
4. Research Goal

Heterogeneous Wireless Networks



Why Personalized Decisions?



Research Motivation

- End users want to use mobile services **simply, conveniently**, and **with high quality** based on their own **preferences** without considering handover (supporting ***Always-Best-Connected (ABC)***) in the given environment
- Common end **users do not have much knowledge** about access network technologies and mobile services
- Most end users **do not want to be disturbed by handover decisions** when they are using mobile services.

Autonomic and Personalized Handover Decisions

Problem Definition

❖ Current solutions lack

- Personalized handover decision, where the goal is to best satisfy the end-user's needs
- Flexibility for accommodating horizontal and vertical handovers
- Move from ABC to ABS (Always Best Satisfying) to CABS (Context-aware ABS)

❖ Current solutions could benefit from

- An autonomic management architecture to govern handover decisions
- An information model to enable different data to be combined to make intelligent handover decisions
- Considering multiple service requirements for handover decisions

Research Goal

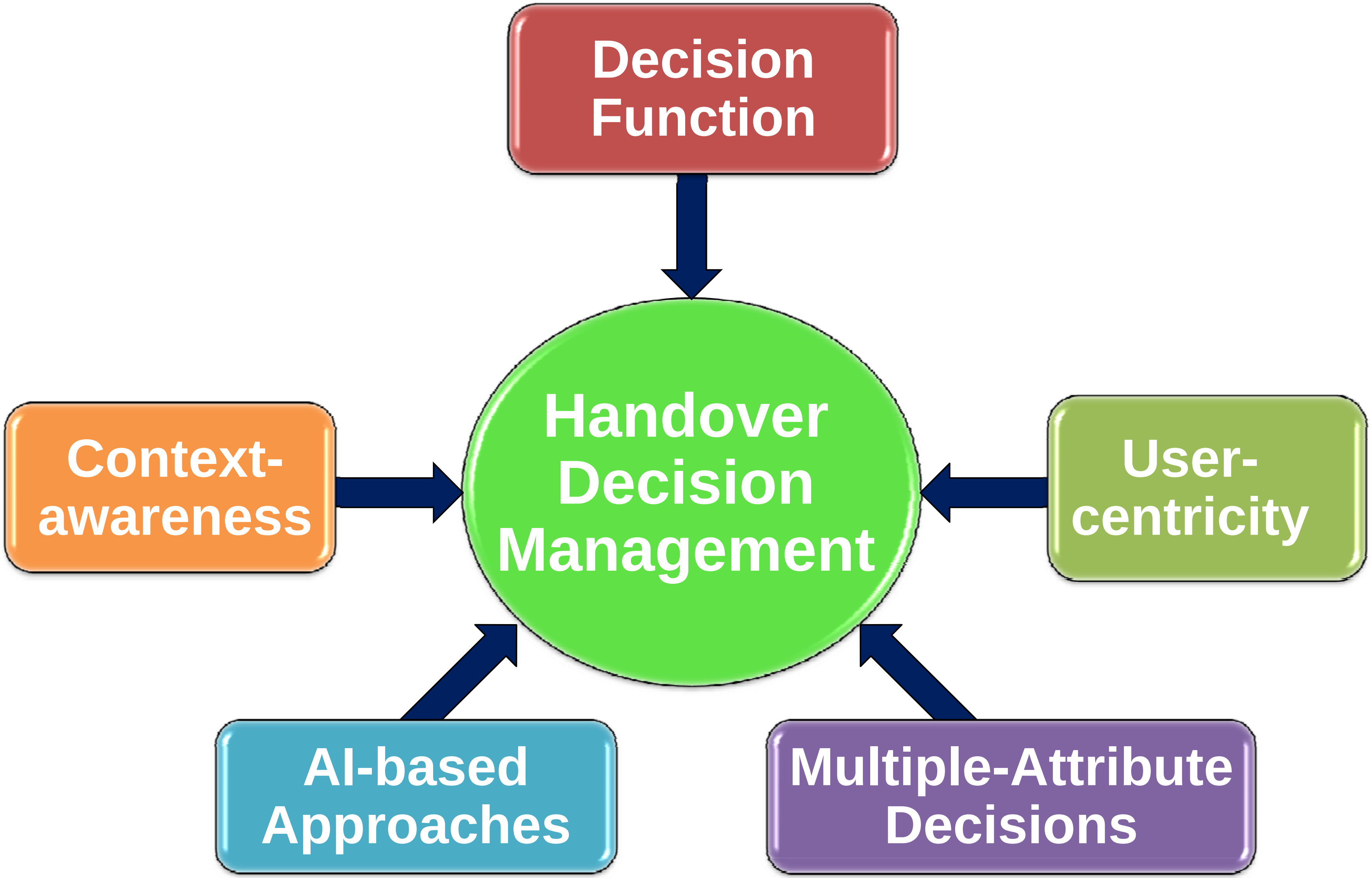
- We propose a **novel autonomic handover decision method (AUHO)** for satisfying the end user's demand (**personalization**) for different types of services in heterogeneous wireless networks

- Our proposed method supports **Context-aware Always-Best-Satisfying (CABS)** handover decision as well as ABC (Always-Best-Connected) by focusing on **functional** and **non-functional** requirements

- We develop a **network simulator** for easily testing the **quality** and **validity** of **L7 handover decision algorithms**

Related Work

Related Work



Comparison with Previous Work

Handover Decision	Traditional (RSS-based)	DF	UC	MAD	AI	CA	AUHO (Proposed)
Multi-criteria	No	Yes	Yes	Yes	Yes (FL) No (NN)	Yes	**Yes**
User consideration	No	Low	High	Medium	Medium	High	**High**
Efficiency	Low	Medium	Medium	High	High	High	**High**
Flexibility	Low	High	High	High	Medium	High	**High**
Implementation complexity	Low	Low	Low	Medium	High	Medium	**High**
Service type supported	Non-real-time	Non-real-time and real-time	Non-real-time	Non-real-time and real-time	Non-real-time and real-time	Non-real-time and real-time	**Multiple types of services**
Personalization	No	No	Yes	No	No	No	**Yes**
Feedback control loop	No	No	No	No	No	Yes	**Yes**
Objective	FR	FR	NFR	FR	FR	FR	**FR & NFR**

DF: decision function, UC: user-centric, MAD: multiple attribute decision,
AI: AI-based approach, CA: context-aware,
AUHO: autonomic handover decision
FR: Functional Requirements, NFR: Non-Functional Requirements

Solution Approach

1. Research Hypothesis
2. Assumptions
3. Methodology
4. Conceptual Approach
5. Context for Handover Decisions

Research Hypothesis

> *Our **AUHO** method always maximizes end user satisfaction of handover decisions for different types of mobile services in heterogeneous wireless networks*

Assumptions

❖ Mobile device

- Multiple active network-enabled applications
- Multiple network interfaces for connecting to multiple available access networks and access points

❖ Network

- We can use any mobile service, regardless of specific network operators or service providers
- Network operator will charge data used in transferring for handover decisions

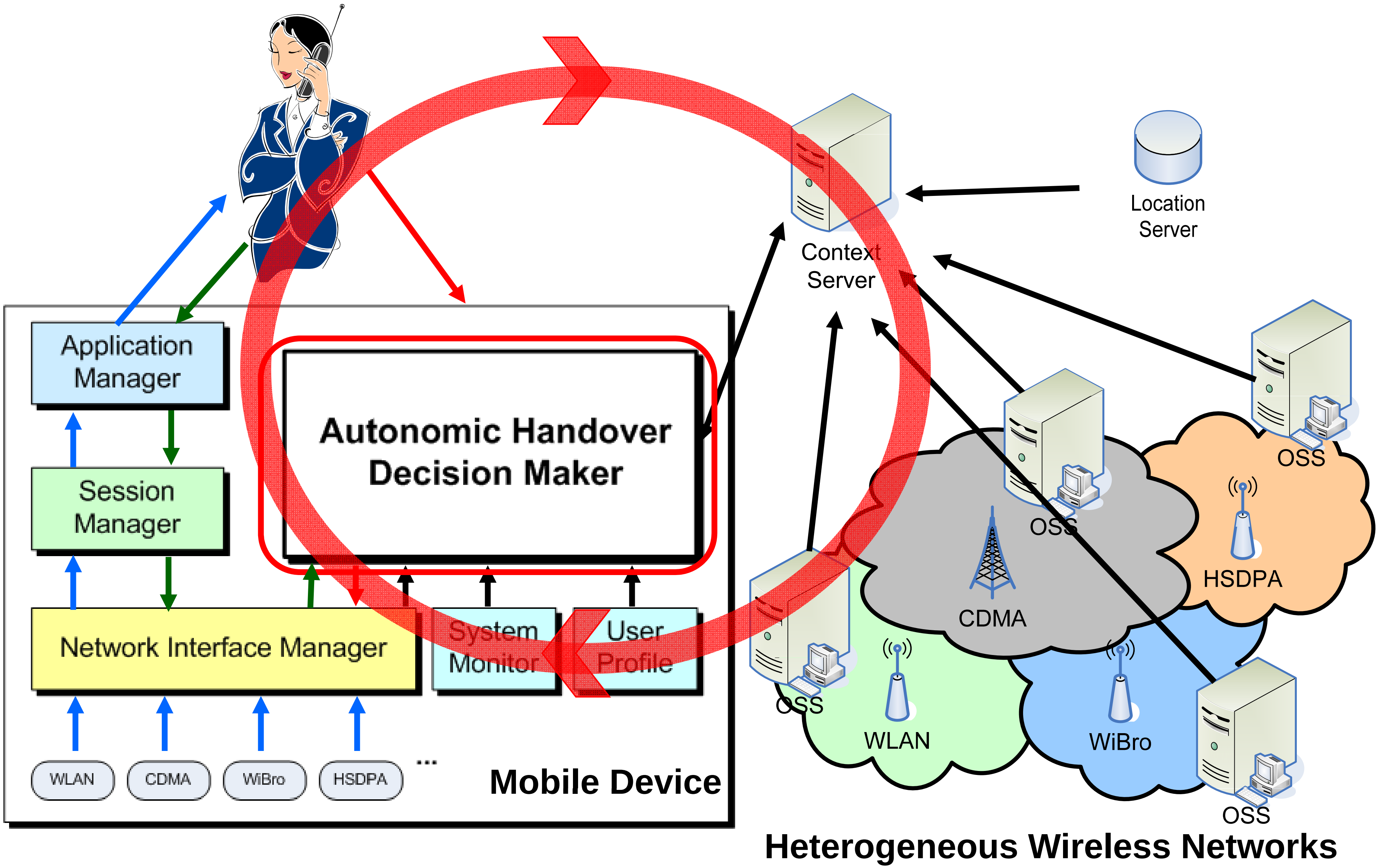
❖ User

- Users can set their preferences by setting policies

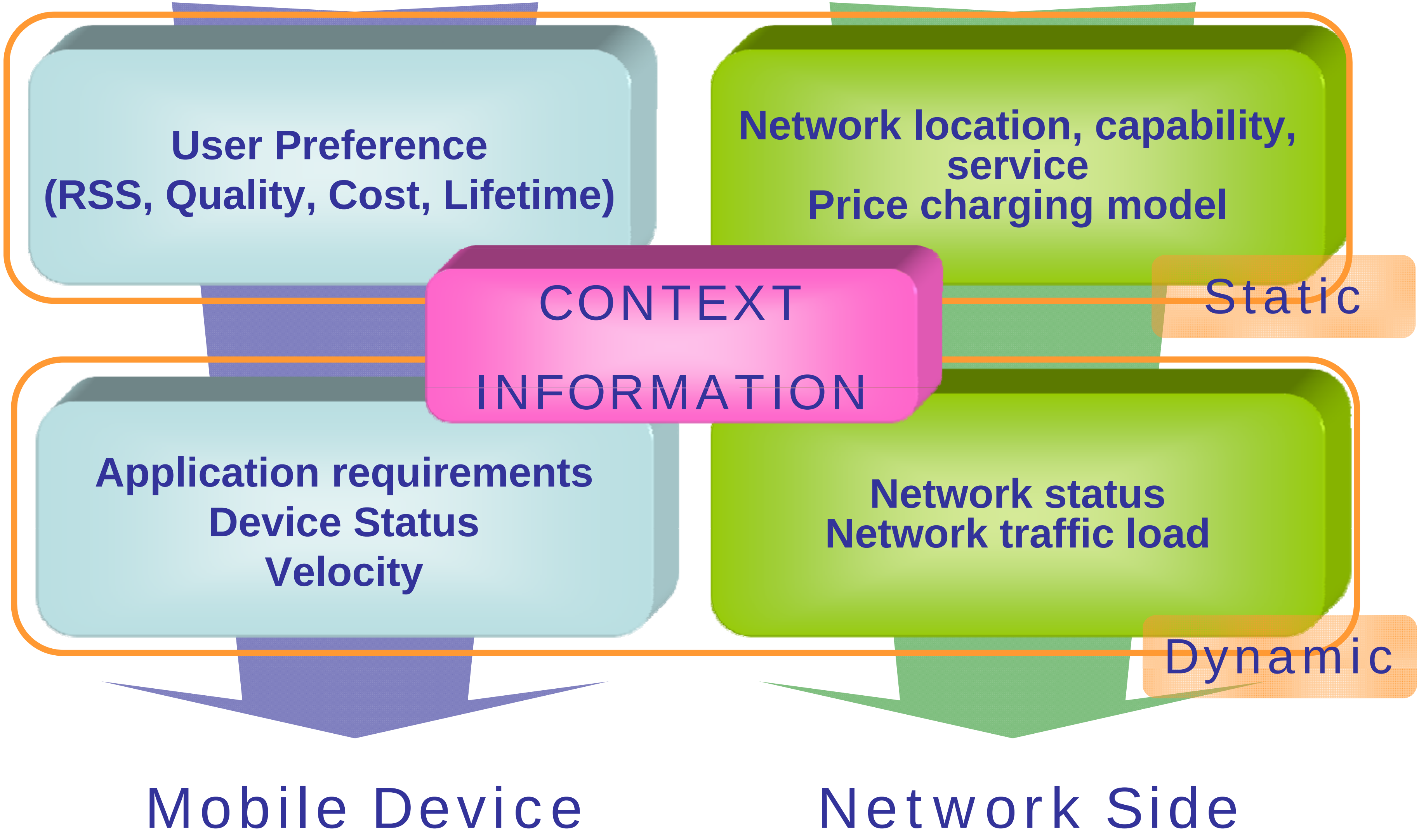
Methodology

- ❖ Extend **DEN-ng** for representing knowledge for handover decisions
- ❖ Define how to measure and evaluate **end user satisfaction**
- ❖ Use a **fuzzy logic** to process all available context information which has different types of values
- ❖ Use **utility function** to calculate satisfaction value for each access network
- ❖ Define an **adaptive feedback control loop** for autonomic management
- ❖ Develop a **network simulator** for testing efficiency of the proposed handover decision

Conceptual Approach



Context for Handover Decisions



Autonomic Personalized Handover Decision Management

1. Policy Definition
2. Proposed AUHO algorithm

Policy for Handover Decision

- Notation of User Profile (UP)
  - $UP = (W_R, W_Q, W_C, W_L)$
- Notation of Policy (P)
  - P = (Event, Condition, Action)
- Example of P
  - Event=VoIP
    - WHEN service starts, IF location=home, THEN UP=(0.40,0.40,0.1,0.1)
  - Event=VoIP
    - WHEN service starts, IF location=office, THEN UP=(0.7,0.1,0.1,0.1)
  - Although we use the same service, user preference can be different by the current context such as location.
- Metrics for evaluating each user preference
  - Cost: different cost model
  - Quality: Bandwidth, Delay, Jitter, BER, Throughput, Burst err, Packet Loss Ratio (PLR)
  - Lifetime: Tx, Rx, Idle power consumption of NIC

Proposed Algorithm (1/3)

❖ Input

- Network interface list, current application

❖ Output

- The best satisfying network interface and the best satisfying AP

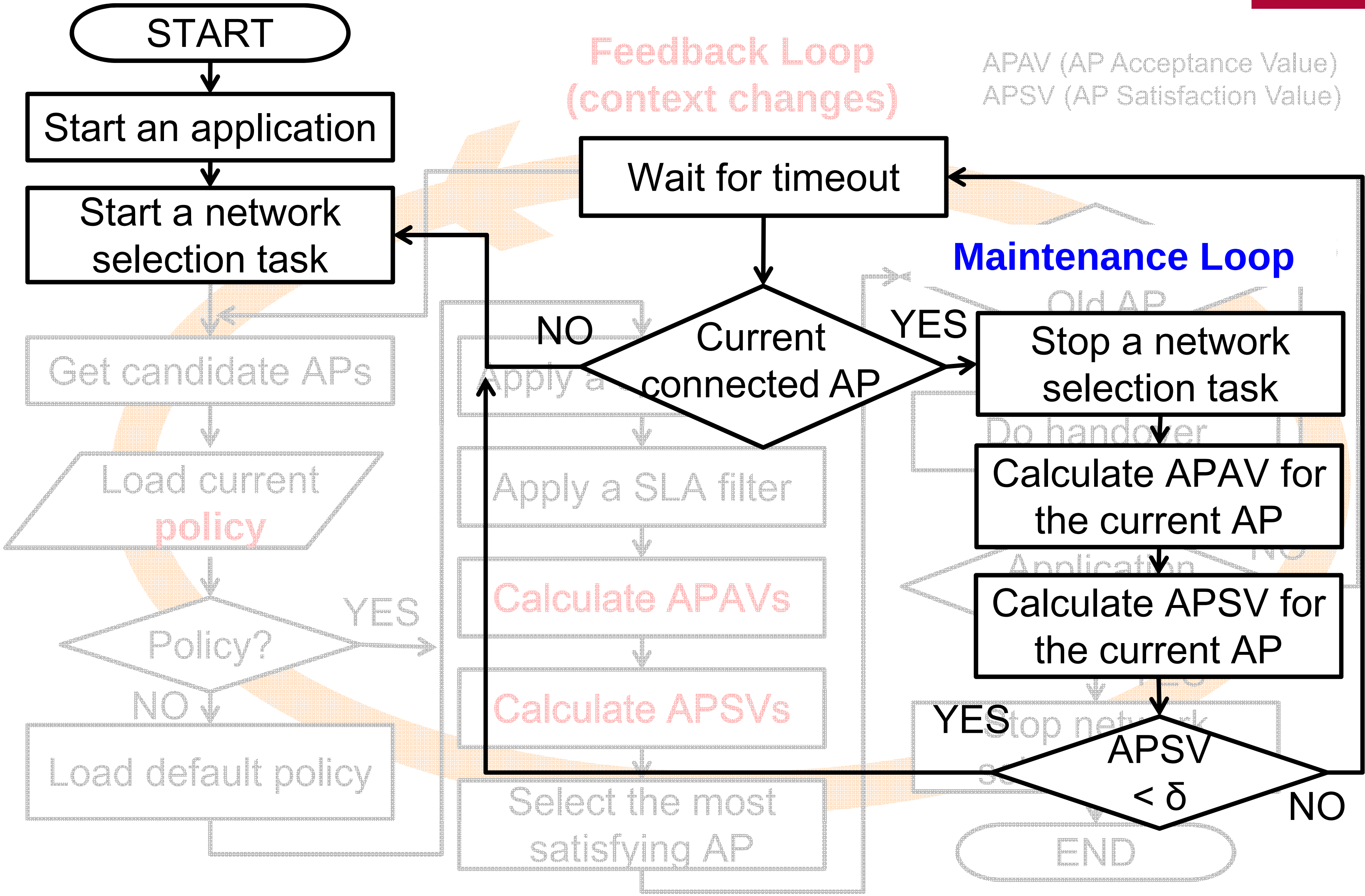
❖ Evaluation Metrics

- AP Acceptance Value (APAV) represents suitability of a particular AP for an end user based on a given set of user preferences (e.g., RSS, Quality, Cost, and Lifetime) [0.0 ~ 1.0]
- AP Satisfaction Value (APSV) represents how well a particular AP satisfies the needs of the end user based on his or her user profile. We can calculate based on APAVs [0.0 ~ 1.0]

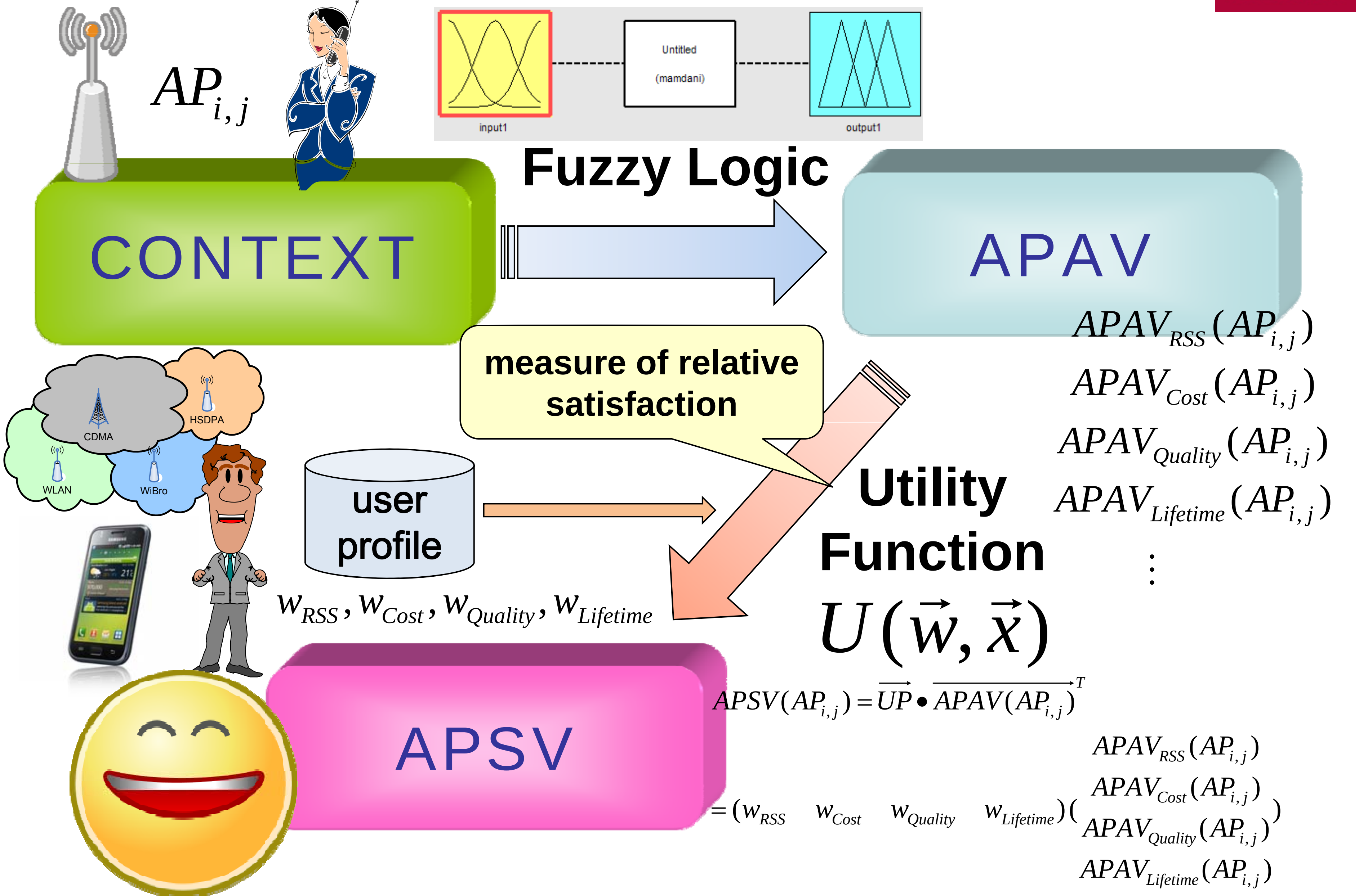
❖ Goal

- Maximize End User Satisfaction (APSV)

Proposed Algorithm (2/3)



Proposed Algorithm (3/3)



Development of HMNToolSuite

HMNToolSuite

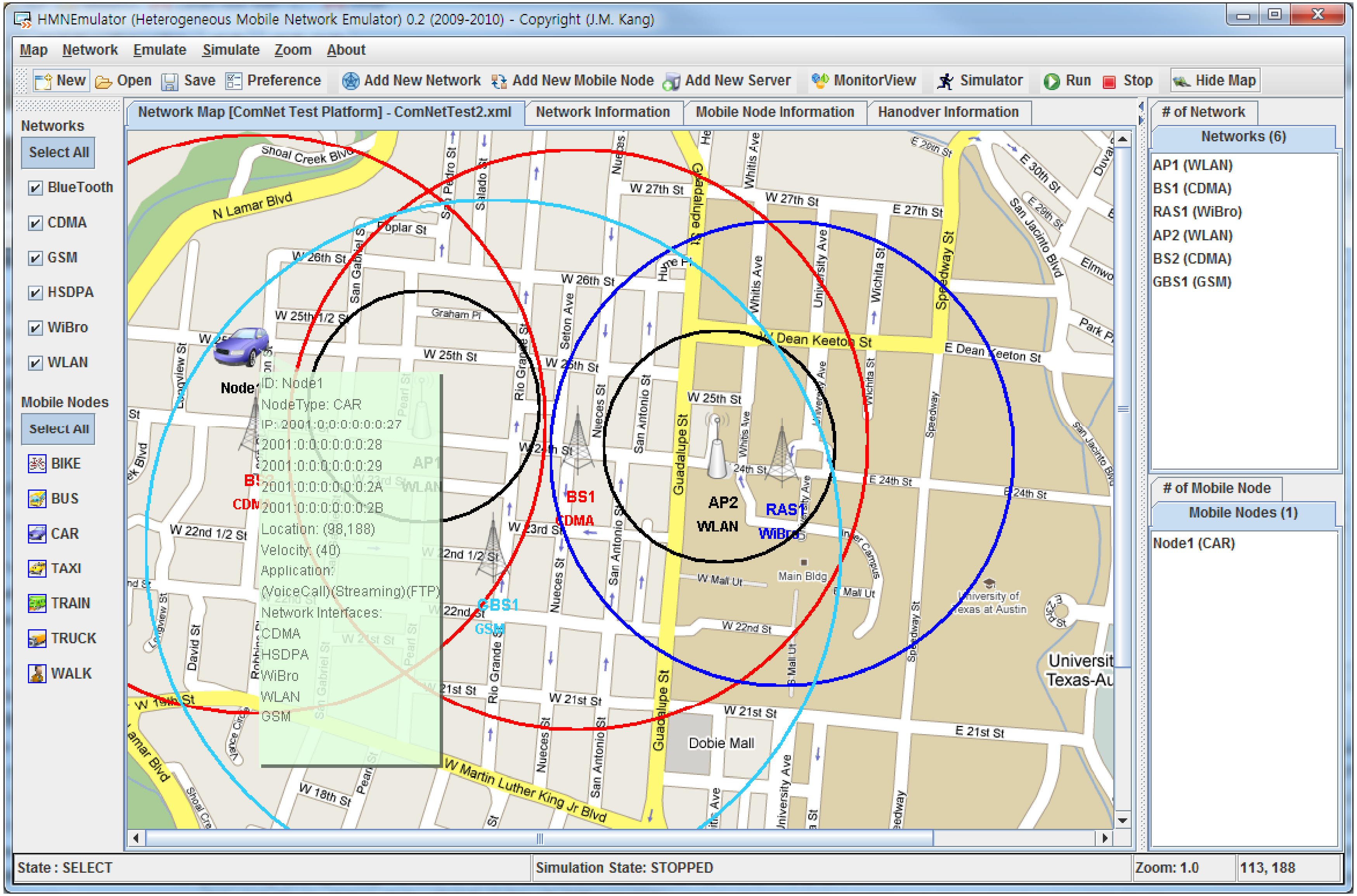
❖ Emulation and Simulation System for Heterogeneous Mobile Networks

- Open source available at http://code.google.com/p/hmntoolsuite
- Collaboration with Prof. Don Batory at UT@Austin (2008-2009)

❖ Main Features

- Heterogeneous mobile network map creator and emulator
  - Create/modify/export network maps
  - Add/modify/delete wireless access networks and mobile nodes
  - Create new mobile nodes based on feature models
  - Create/modify/open/save simulation scenarios
  - Create/modify/delete handover decision policies for mobile nodes
- Heterogeneous mobile network simulator
  - Open a network map (created by the network map creator)
  - Visualize the path taken by mobile nodes
  - Support the simulation of key operational characteristics of networks defined in the network map
  - Support the simulation of detecting available networks
  - Support CLI-based simulation

HMNToolSuite



Evaluations and Results

1. Experimental Setup
2. Results

Experimental Setup (1/3)

❖ Hypothesis

- Our **AUHO** method always maximizes end user satisfaction of handover decisions for different types of mobile services in heterogeneous wireless networks

❖ Method

- Compare our AUHO algorithm to other standard algorithms: Random, RSS-based, Cost-based, Quality-based, and Lifetime-based

❖ Measurement metrics

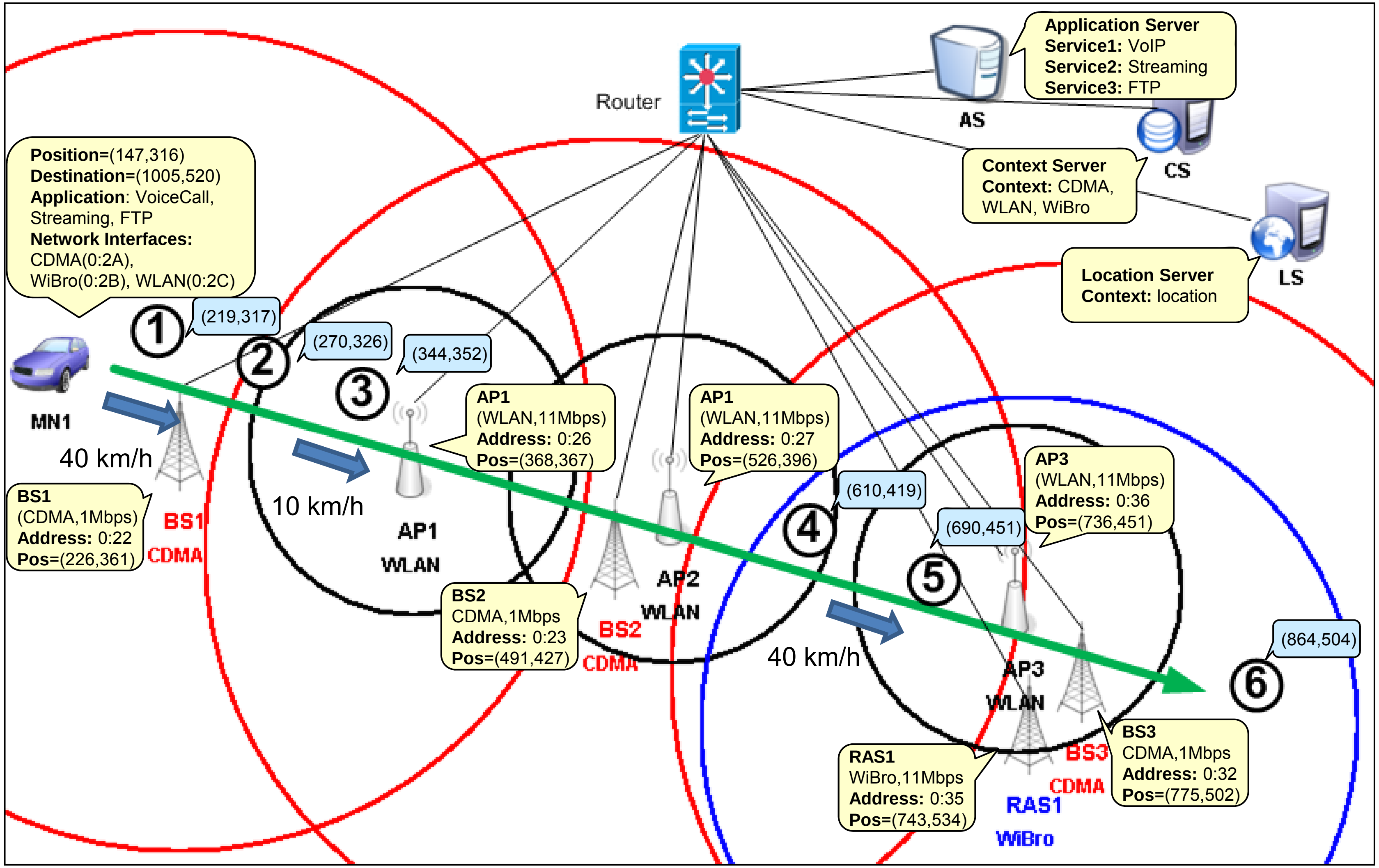
- Quality, cost, lifetime, end user satisfaction

Experimental Setup (2/3)

❖Two case studies

- Same application with different user profiles
  - Voice call with Cost and Quality
  - Voice call with Quality and Lifetime
  - Voice call with Cost, Quality, and Lifetime
  - Streaming …
  - FTP …
- Different applications with a same user profile
  - Voice call with Cost and Quality
  - Streaming with Cost and Quality
  - FTP with Cost and Quality
  - Voice call with Quality and Lifetime
  - …

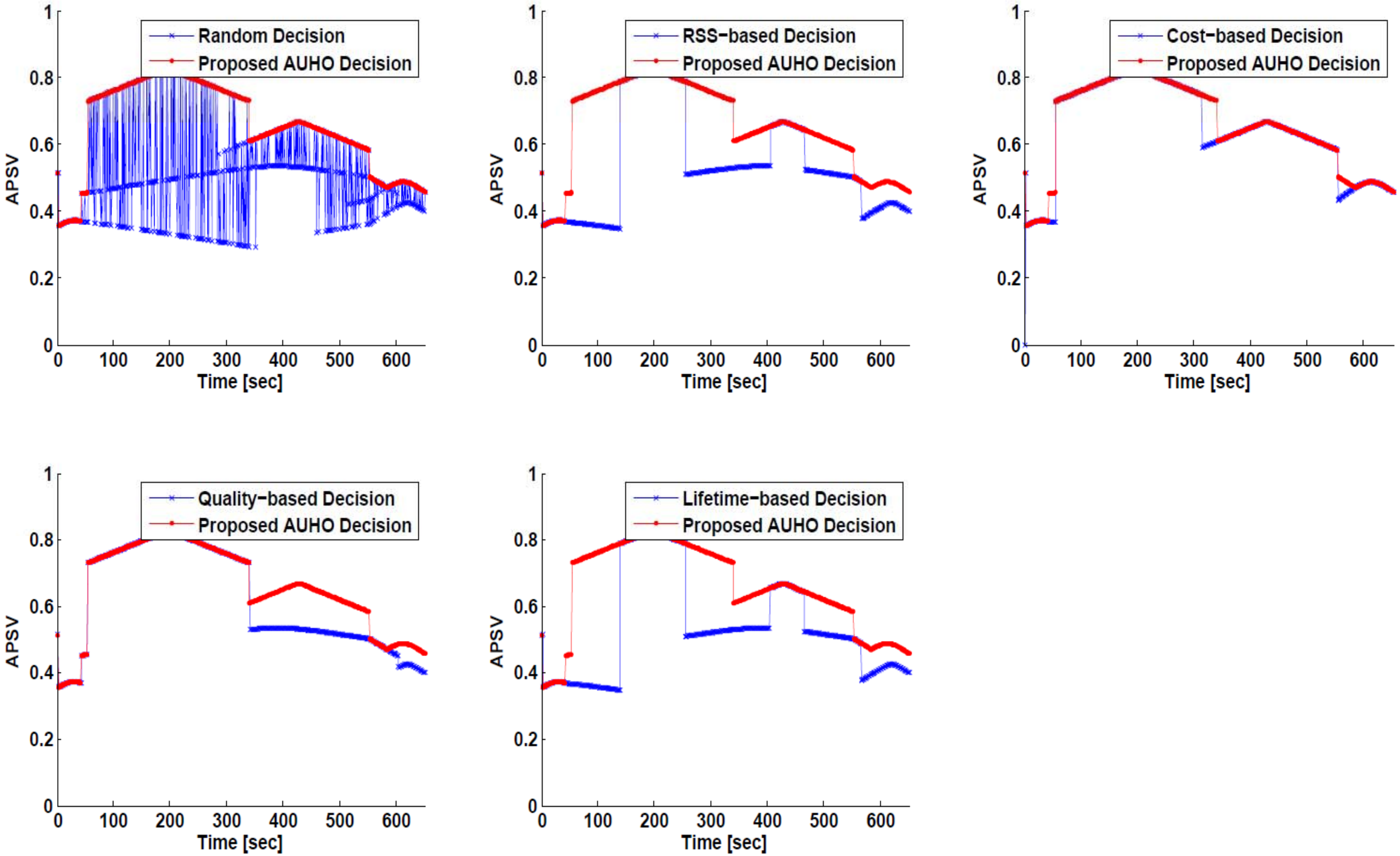
Experimental Setup (3/3)



Results – Voice call & CQ (1/2)

Location	1	2	3	4	5	6
Simulation Time (sec)	25	44	157	553	585	651
Available Access Networks (AP)	CDMA(BS1)	CDMA(BS1, BS2)	CDMA(BS1,BS2), WLAN(AP1)	CDMA(BS2,BS3), WLAN(AP2), WiBro(RAS1)	CDMA(BS2,BS3), WLAN(AP3), WiBro(RAS1)	CDMA(BS3), WiBro(RAS1)
Speed Filtering (AP)	CDMA(BS1)	CDMA(BS1, BS2)	CDMA(BS1,BS2), WLAN(AP1)	CDMA(BS2,BS3), WLAN(AP2), WiBro(RAS1)	CDMA(BS2,BS3), WiBro(RAS1)	CDMA(BS3), WiBro(RAS1)
SLA Filtering (AP)	CDMA(BS1)	CDMA(BS1, BS2)	CDMA(BS1,BS2), WLAN(AP1)	CDMA(BS2,BS3), WLAN(AP2), WiBro(RAS1)	CDMA(BS2,BS3), WiBro(RAS1)	CDMA(BS3), WiBro(RAS1)
AP ($APAV_R$)	BS1(0.816)	BS1(0.779), BS2(0.019)	BS1(0.530),BS2(0.335),AP1(0.703)	BS3(0.256),BS2(0.527), RAS1(0.114),AP2(0.141)	BS3(0.598),BS2(0.203), RAS1(0.501)	BS3(0.652), RAS1(0.385)
AP ($APAV_C$)	BS1(0.100)	BS1(0.100),BS2(0.100)	BS1(0.100),BS2(0.100)AP1(0.800)	BS3(0.100),BS2(0.100),RAS1(0.500)AP2(0.800)	BS3(0.100),BS2(0.100), RAS1(0.500)	BS3(0.100), RAS1(0.500)
AP ($APAV_Q$)	BS1(0.500)	BS1(0.500),BS2(0.900)	BS1(0.500),BS2(0.900)AP1(0.900)	BS3(0.614),BS2(0.900), RAS1(0.500)AP2(0.500)	BS3(0.614),BS2(0.900), RAS1(0.500)	BS3(0.614), RAS1(0.500)
AP ($APAV_L$)	BS1(0.500)	BS1(0.500),BS2(0.500)	BS1(0.500),BS2(0.500)AP1(0.500)	BS3(0.500),BS2(0.500), RAS1(0.203)AP2(0.500)	BS3(0.500),BS2(0.500), RAS1(0.203)	BS3(0.500), RAS1(0.203)
AP (APSV)	BS1(0.372)	BS1(0.368),BS2(0.452)	BS1(0.343),BS2(0.483)AP1(0.800)	BS3(0.361),BS2(0.503), RAS1(0.432)AP2(0.584)	BS3(0.395),BS2(0.470), RAS1(0.470)	BS3(0.401), RAS1(0.459)
Random (best AP)	CDMA(BS1)	CDMA(BS2)	WLAN(AP1)	WLAN(AP2)	CDMA(BS3)	CDMA(BS3)
RSS (best AP)	CDMA(BS1)	CDMA(BS1)	WLAN(AP1)	CDMA(BS2)	CDMA(BS3)	CDMA(BS3)
Cost (best AP)	CDMA(BS1)	CDMA(BS1)	WLAN(AP1)	WLAN(AP2)	WiBro(RAS1)	WiBro(RAS1)
Quality (best AP)	CDMA(BS1)	CDMA(BS2)	WLAN(AP1)	CDMA(BS2)	CDMA(BS2)	CDMA(BS3)
Lifetime (best AP)	CDMA(BS1)	CDMA(BS1)	CDMA(BS1)	CDMA(BS2)	CDMA(BS3)	CDMA(BS3)
AUHO (best AP)	*CDMA(BS1)*	*CDMA(BS2)*	*WLAN(AP1)*	*WLAN(AP2)*	*CDMA(BS2)*	*WiBro(RAS1)*

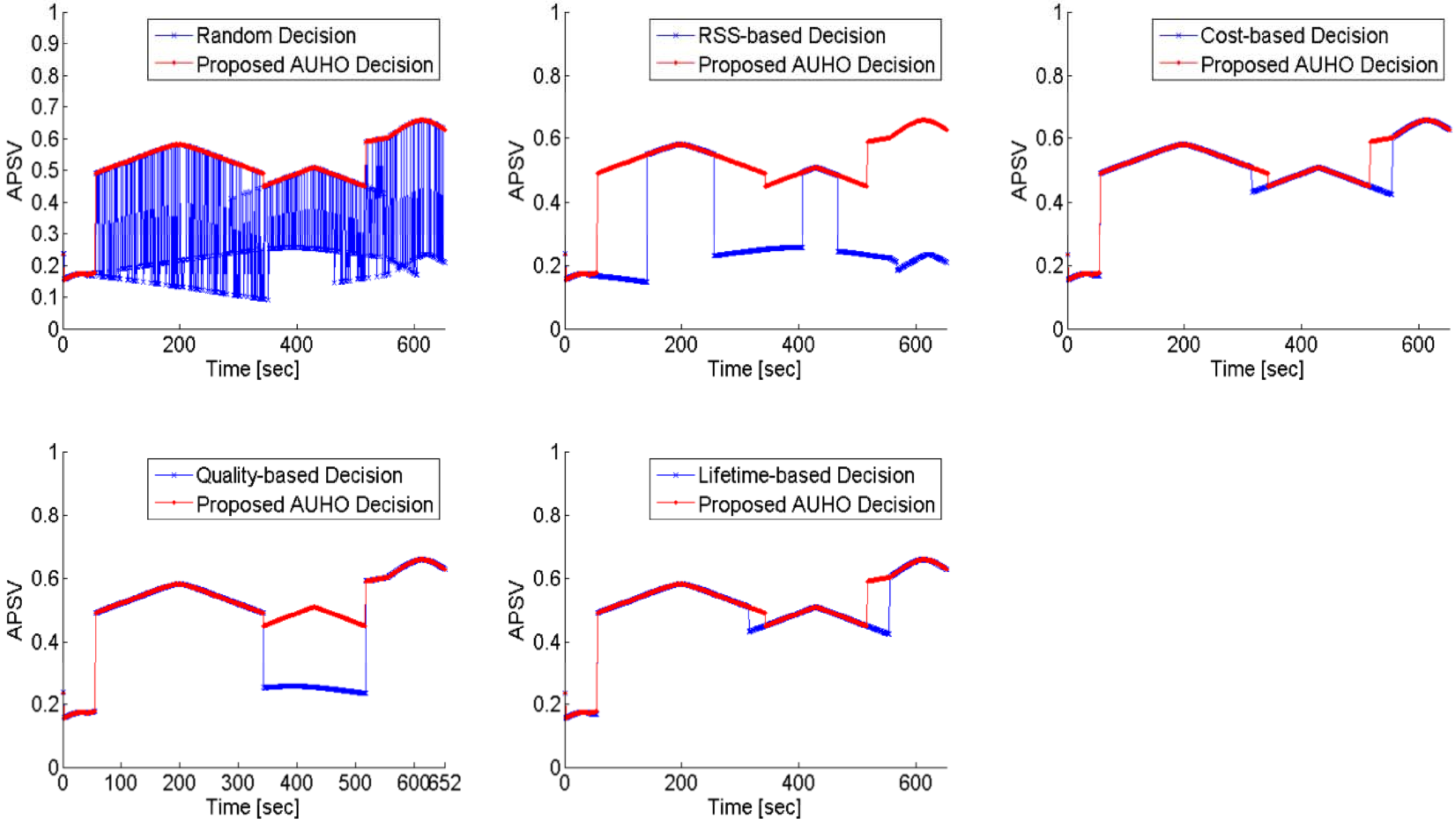
Results – Voice call & CQ (2/2)



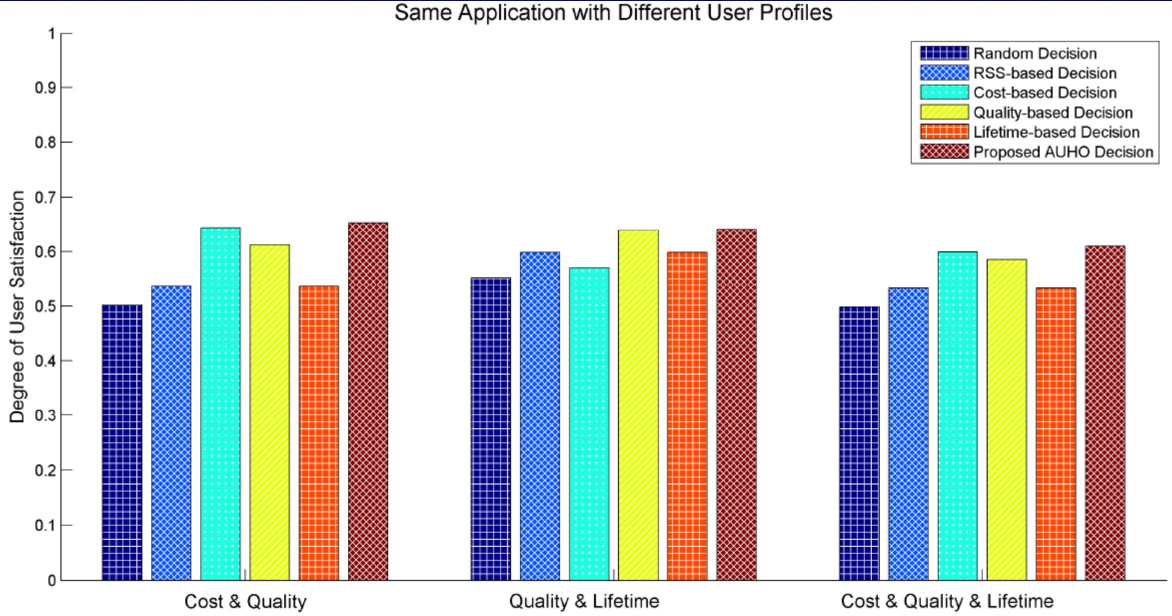
Results – Streaming & CQ (1/2)

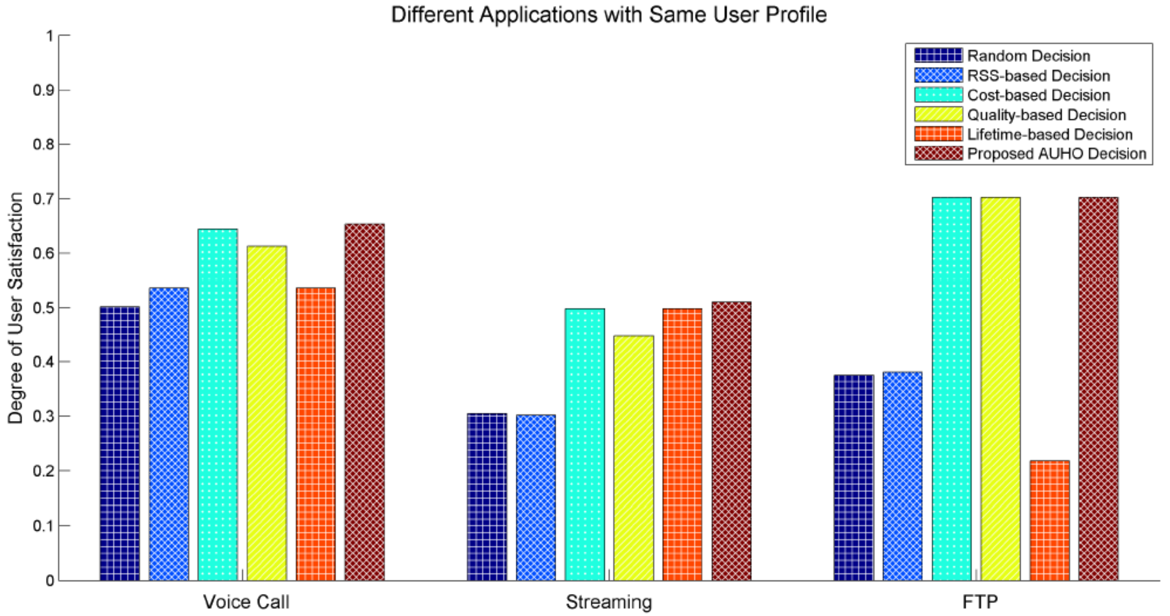
Location in the Map	1	2	3	4	5	6
Simulation Time (sec)	25	44	157	553	585	651
Available Access Networks (AP)	CDMA(BS1)	CDMA(BS1, BS2)	CDMA(BS1,BS2), WLAN(AP1)	CDMA(BS2,BS3), WLAN(AP2), WiBro(RAS1)	CDMA(BS2,BS3), WLAN(AP3), WiBro(RAS1)	CDMA(BS3), WiBro(RAS1)
Speed Filtering (AP)	CDMA(BS1)	CDMA(BS1, BS2)	CDMA(BS1,BS2), WLAN(AP1)	CDMA(BS2,BS3), WLAN(AP2), WiBro(RAS1)	CDMA(BS2,BS3), WiBro(RAS1)	CDMA(BS3), WiBro(RAS1)
SLA Filtering (AP)	CDMA(BS1)	CDMA(BS1, BS2)	CDMA(BS1,BS2), WLAN(AP1)	CDMA(BS2,BS3), WLAN(AP2), WiBro(RAS1)	CDMA(BS2,BS3), WiBro(RAS1)	CDMA(BS3), WiBro(RAS1)
AP ($APAV_R$)	BS1(0.816)	BS1(0.779), BS2(0.019)	BS1(0.530),BS2(0.335), AP1(0.703)	BS3(0.256),BS2(0.527), RAS1(0.114),AP2(0.141)	BS3(0.598),BS2(0.203),RAS1(0.501)	BS3(0.652), RAS1(0.385)
AP ($APAV_C$)	BS1(0.100)	BS1(0.100), BS2(0.100)	BS1(0.100),BS2(0.100) AP1(0.800)	BS3(0.100),BS2(0.100), RAS1(0.500)AP2(0.800)	BS3(0.100),BS2(0.100),RAS1(0.500)	BS3(0.100), RAS1(0.500)
AP ($APAV_Q$)	BS1(0.100)	BS2(0.300), BS1(0.100)	BS2(0.300),BS1(0.100) AP1(0.300)	BS3(0.234),BS2(0.300), RAS1(0.900)AP2(0.100)	BS3(0.234),BS2(0.300),RAS1(0.900)	BS3(0.234), RAS1(0.900)
AP ($APAV_L$)	BS1(0.100)	BS2(0.100), BS1(0.100)	BS2(0.100),BS1(0.100), AP1(0.500)	BS3(0.100),BS2(0.100), RAS1(0.300),AP2(0.500)	BS3(0.100),BS2(0.100),RAS1(0.300)	BS3(0.100), RAS1(0.300)
AP (APSV)	BS1(0.172)	BS2(0.172), BS1(0.168)	BS2(0.203),BS1(0.143), AP1(0.560)	BS3(0.169),BS2(0.223), RAS1(0.601),AP2(0.424)	BS3(0.203),BS2(0.190),RAS1(0.640)	BS3(0.209), RAS1(0.629)
Random (best AP)	CDMA(BS1)	CDMA(BS1)	WLAN(AP1)	CDMA(BS3)	WiBro(RAS1)	WiBro(RAS1)
RSS (best AP)	CDMA(BS1)	CDMA(BS1)	WLAN(AP1)	CDMA(BS2)	CDMA(BS3)	CDMA(BS3)
Cost (best AP)	CDMA(BS1)	CDMA(BS1)	WLAN(AP1)	WLAN(AP2)	WiBro(RAS1)	WiBro(RAS1)
Quality (best AP)	CDMA(BS1)	CDMA(BS2)	WLAN(AP1)	WiBro(RAS1)	WiBro(RAS1)	WiBro(RAS!)
Lifetime (best AP)	CDMA(BS1)	CDMA(BS1)	WLAN(AP1)	WLAN(AP2)	WiBro(RAS1)	WiBro(RAS1)
AUHO (best AP)	**CDMA(BS1)**	**CDMA(BS2)**	**WLAN(AP1)**	**WiBro(RAS1)**	**WiBro(RAS1)**	**WiBro(RAS1)**

Results – Streaming & CQ (2/2)



Results – summary





Conclusions

1. Summary
2. Contributions
3. Future Work

Summary

- We proposed a **novel autonomic management method** for **personalized handover decisions** using context information, application requirements, and user profiles
- Our AUHO determined the **best satisfying AP** of the **best satisfying access network** (both horizontal and vertical handover decisions) for a programmable set of user preferences and profiles
- Our method outperformed other handover decision methods in terms of **end user satisfaction**
- We also developed a **unique and user-friendly L7 network simulation tool** for testing handover decisions in heterogeneous wireless networks

Contributions

- Provides an autonomic management architecture that can deliver personalized handover decisions for heterogeneous wireless networks
- Provides a novel decision method by using a hybrid approach of context-aware, user-centric, multiple-attribute, and fuzzy logic based approaches.
- Optimizes end user satisfaction for personalized handover decisions in terms of functional and non-functional requirements
- Provides *seamless personalized roaming* by monitoring the current context (e.g., location, time, and/or tasks being performed)
- Provides a network simulator for testing handover decision algorithms in heterogeneous wireless networks, which anyone can use for testing and comparing other handover decision algorithms

Future Work

- ❖ **Fuzzy logic optimization for calculating APAVs**
- ❖ **Optimization of weight values for building user profiles**
- ❖ **Enhancement of our autonomic decision architecture using ontology and semantic reasoning**
- ❖ **More tests and optimization with considering handover overhead and network performance**

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PhD Thesis Defense, Joon-Myung Kang

December 20, 2010

Publications (1/4)

❖ International Journal Papers (4)

1. **<u>Joon-Myung Kang</u>**, John Strassner, Sin-seok Seo, and James Won-Ki Hong, *Autonomic Personalized Handover Decision for Mobile Services in Converged Networks*, Submitted to Computer Networks, Elsevier (reviewing the first revision) (SCIE)
2. Chang-Keun Park, **<u>Joon-Myung Kang</u>**,JamesWon-Ki Hong, Mi-Jung Choi, Yong-hun Lim, Seongho Ju, and Moon-suk Choi. *Development and Testing of an SNMP-based Integrated Management System for Heterogeneous Power Line Communication Networks*. International Journal of Network Management (IJNM), Vol. 20, Issue 1, January/February 2010, pp. 35-55. (SCIE)
3. **<u>Joon-Myung Kang</u>**, Hong-Teak Ju, Mi-Jung Choi, James Won-Ki Hong, and Jun-Gu Kim, *OMA-DM Based Software Fault Management of Mobile Devices*, International Journal of Network Management (IJNM), Vol. 19, Issue 6, November/December 2009, pp. 491-511.(SCIE)
4. Jae-Jo Lee, Choong Seon Hong, **<u>Joon-Myung Kang</u>**, and James Won-Ki Hong, *Power line communication network trial and management in Korea*, International Journal of Network Management (IJNM), Vol. 13, Issue 6, Special Issue, November/December 2006, pp. 443-457.

Publications (2/4)

- **International Conference Papers (9)**

1. Sin-seok Seo, **Joon-Myung Kang**, Nazim Agoulmine, John Strassner, James Won-Ki Hong, *FAST: A Fuzzy-based Adaptive Scheduling Technique for IEEE 802.16 Networks*, Accepted to appear in IM 2011
2. Arum Kwon, **Joon-Myung Kang**, Sin-seok Seo, Sung-Su Kim, Jae Yoon Chung, John Strassner and Jame Won-Ki Hong. *The Design of a Quality of Experience Model for Providing High Quality Multimedia Services*, The 5th IEEE International Workshop on Modelling Autonomic Communication Environments (MACE 2010) Niagara Falls, Canada, Oct. 2010, pp. 24-36.
3. **Joon-Myung Kang**, Chang-Keun Park, Sin-Seok Seo, Mi-Jung Choi, and Jame Won-Ki Hong. *User-Centric Prediction for Battery Lifetime of Mobile Devices*. 11th Asia-Pacic Network Operations and Management Symposium (APNOMS 2008), LNCS 5297, Beijing,China, Oct. 2008, pp. 531-534.
5. **Joon-Myung Kang**, Hong-Teak Ju, Mi-Jung Choi, and James Won-Ki Hong. *OMADM Based Remote RF Signal Monitoring of Mobile Devices for QoS Improvement*. 10th IFIP/IEEE International Conference on Management of Multimedia and Mobile Networks and Services (MMNS 2007), LNCS 4787, San Jose, CA, USA, Oct. 2007, pp. 76-87.
6. **Joon-Myung Kang**, Hong-Teak Ju, Mi-Jung Choi, and James Won-Ki Hong. *OMA DM Based Remote Software Debugging of Mobile Devices*. 10th Asia-Pacic Network Operations and Management Symposium (APNOMS 2007), LNCS 4773, Sapporo, Hokkaido, Japan, Oct. 2007, pp. 51-61.
7. **Joon-Myung Kang**, Hong-Teak Ju, and James Won-Ki Hong. *Towards Autonomic Handover Decision Management in 4G Networks*. 9th IFIP/IEEE International Conference on Management of Multimedia and Mobile Networks and Services (MMNS 2006), LNCS 4267, Dublin, Ireland, Oct., 2006, pp. 145-157

- **Domestic Journal Papers (2), Domestic Conference Papers (10)**

Publications (3/4)

❖ International Patents (US-3, EPO-3, Japan-3)

1. *Method and Apparatus for Handover decision by using Context Information in a Next-Generation Mobile Communications Network*. Patent No.: 4571663, Japan, 2010.08.20
2. Method and Apparatus for Detecting Abnormal Battery Consumption of Mobile Devices. Patent No.:09005896.7, Europe(EPO), 2009. (Applicant: POSTECH) (Accepted to register)
3. Method for Predicting Battery Lifetime of Mobile Devices Based on Usage Patterns. Patent No.: 2009-118340, Japan, 2009. (FILED)
4. Method and Apparatus for Detecting Abnormal Battery Consumption of Mobile Devices. Patent No.: , Japan, 2009. (Applicant: POSTECH) (FILED)
5. Method for Predicting Battery Lifetime of Mobile Devices Based on Usage Patterns. Patent No.:12/453,141, USA, 2009. (Applicant:POSTECH) (FILED)
6. Method and Apparatus for Detecting Abnormal Battery Consumption of Mobile Devices Patent No.:12/453,142, USA, 2009. (Applicant:POSTECH) (FILED)
7. *Method and Apparatus for Handover decision by using Context Information in a Next-Generation Mobile Communications Network*.Patent No.: 11/907,547, USA, 2007.10.15 (Applicant: POSTECH) (FILED)
8. Method for Predicting Battery Lifetime of Mobile Devices Based on Usage Patterns. Patent No.:09005895.9, Europe(EPO), 2009. (FILED)
9. *Method and Apparatus for Handover decision by using Context Information in a Next-Generation Mobile Communications Network*.Patent No.: 07020430.0-1249, Europe (EPO), 2007.10.18 (Applicant: POSTECH) (FILED)

Publications (4/4)

❖ Domestic Patents (7) – 3 Registered

1. Method for Predicting Available Time Remaining on Battery in Mobile Devices Based on Usage Patterns, Patent No. 10-0981128, 2009.05.27
2. Method and Apparatus for Detecting Abnormal Power Consumption of a Battery in Mobile Devices, Patent No.:10-0969567, 2010.07.05
3. *Method and Apparatus for Handover decision by using Context Information in a Next-Generation Mobile Communications Network*, Patent No.: 10-0809260, 2008.02.25
4. *Method for Decisioning Personalized Handover of Mobile Terminal and Mobile Terminal Performing the Same*, Patent No. 10-2010-0081790, 2010.08.24 (FILED)
5. Method of Automated Answering in Mobile Communication System and Apparatus for the Same, Patent No.: 10-2010-0081790, Korea, 2010.08.24 ((FILED)
6. Method for Providing Autonomic Management of Software System, Recording Medium Storing Program for Performing the Same and System Having Function of Autonomic Management of Software, Patent No.: 10-2010-0032564, Korea, 2010.04.09 (FILED)
7. Method and Apparatus for Providing and Managing Personalized Services, Patent No.: 10-2010-0033286, Korea, 2010.04.12 (FILED)

❖ Programs (11) – Registered in Korea

Appendix I

Handover

Heterogeneous Wireless Networks

❖ Different access networks

- WiFi, CDMA, HSDPA, WiBro, Bluetooth, etc.

❖ Different user premises

- Smart phone, tablet, laptop, etc.

❖ Different user demands

- quality, cost, lifetime, etc.

❖ Different service requirements

- delay, jitter, packet loss, etc.

❖ Different environmental conditions

- location, time, etc.

Seamless Mobility

- Simple, uninterrupted access to any type of information desired at any time, independent of place, network, and device

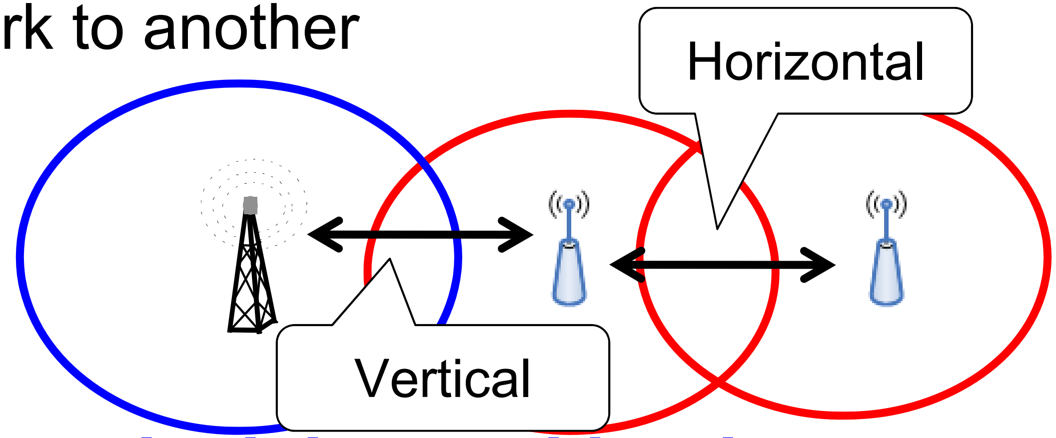
- Seamless handover protocol
  - e.g. IEEE 802.21 Media Independent Handover, Mobile IP etc.

- Handover decision making algorithm
  - E.g. received signal strength

Handover in HWN

❖ Handover (or handoff)

- Process of transferring an ongoing call or data session from one channel connected to the current network to another



❖ Handover decision making in HWN

- Which access network (or access point) is the best (or optimal)?
- Received signal strength based decision (traditional)
- Always-Best-Connected (ABC)

Handover Process

Mobility Scenarios
Horizontal
Vertical

Handover Types
Hard, Soft
Seamless
Fast, Smooth
Etc

Handover Control
Network-Controlled HO
Mobile-Controlled HO
Network-Assisted HO
Mobile-Assisted HO

Handover Performance
HO Latency
Packet Loss Rate
Throughput
Ping-Pong Effect
Etc.

Handover Management Process

Handover Information Gathering

Handover Decision

Handover Execution

Handover Decision Criteria
RSS
Velocity
User Preferences
QoS Parameters
Battery Status
Etc.

Handover Decision Strategies
Traditional (RSS)
Function-based
User-Centric
Fuzzy Logic-based
Neural Network-based
Multiple Attribute
Context-Aware
Hybrid

Appendix II

Related Work Details

Related Work (1/5)

❖Decision function-based strategies [1-6]

- The general form of the cost function f_n of wireless network *n* is [2]

$$f_n = \Sigma_s \Sigma_i w_{s,i} \cdot p^{n}_{s,i}$$

  - $p^n_{s,i}$: the cost in the ith parameter to carry out service *s* on network *n*
  - $w_{s,i}$: the weight (importance) assigned to using the ith parameter to perform services (with $\Sigma_i w_i = 1$)

Related Work (2/5)

❖User-centric strategies [7-13]

- User preference (cost, QoS)
- Utility function
- Cost function example [7]

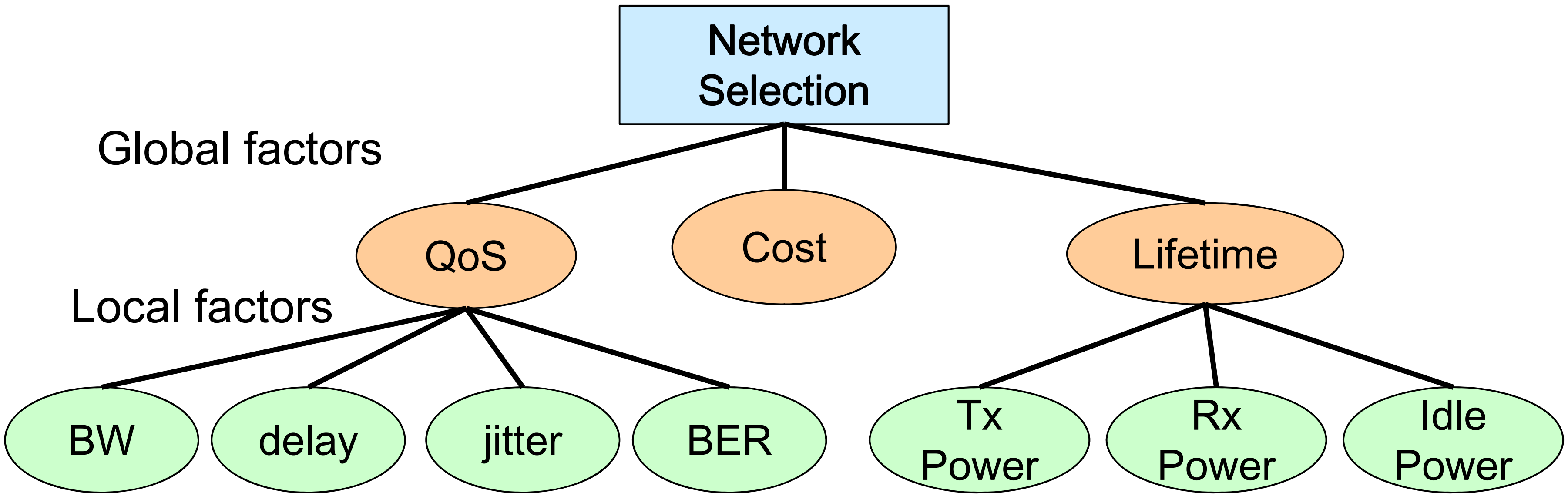
$$C = T_{\mathrm{WiFi}} \cdot c_{\mathrm{WiFi}}(h) + T_{\mathrm{GPRS}} . c_{\mathrm{GPRS}}(h)$$

- T_i : the time spent by the user in the ith access network
- $c_i(h)$: the fee per unit of time (second) that the operator of the ith access network charges to the user
- C : the monetary cost faced by the user for a given communication session

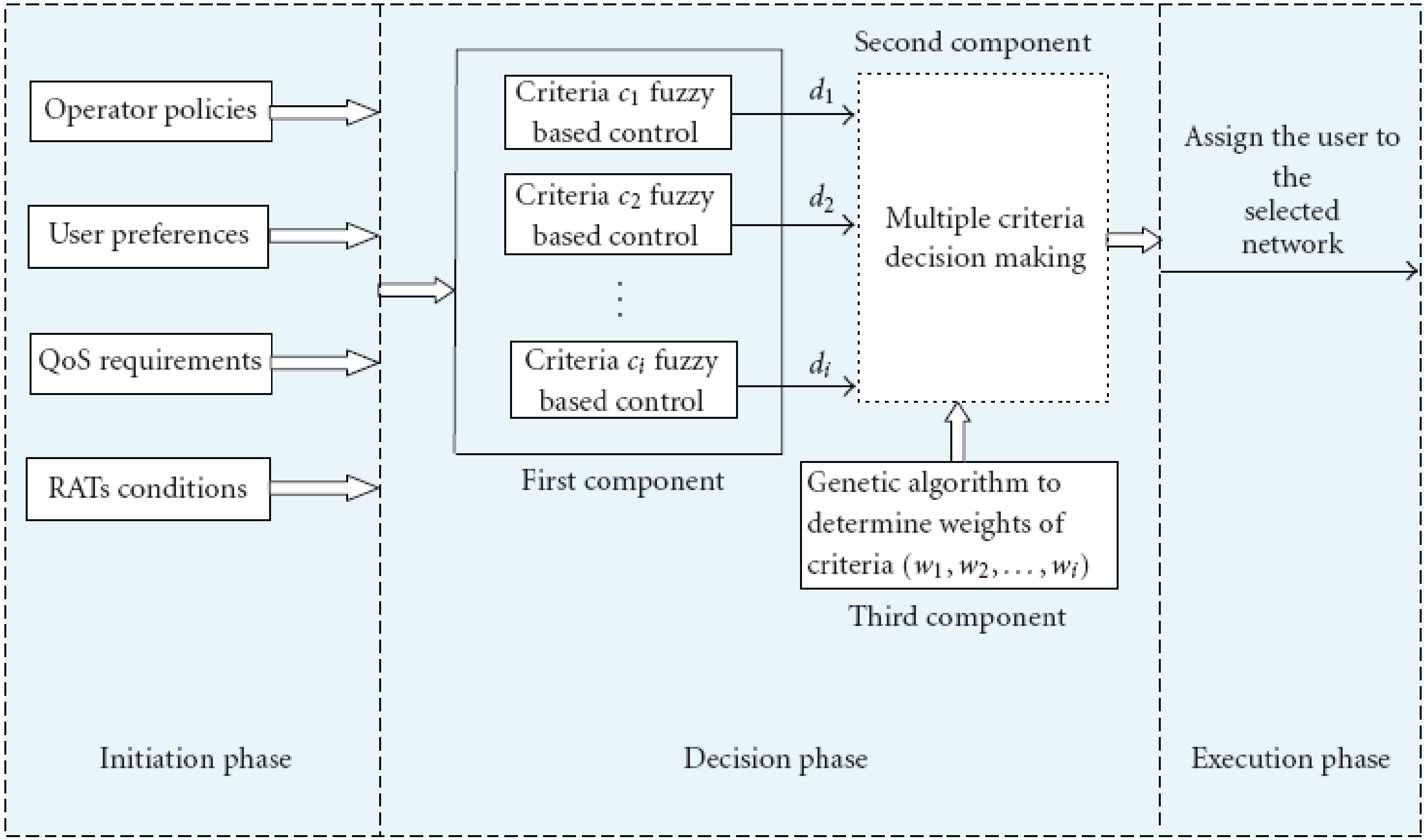
Related Work (3/5)

❖Multiple attribute decision strategies [14-18]

- AHP (Analytic Hierarchy Process)
  - Decomposes the network selection problem into several sub-problems and assigns a weight to each sub-problem



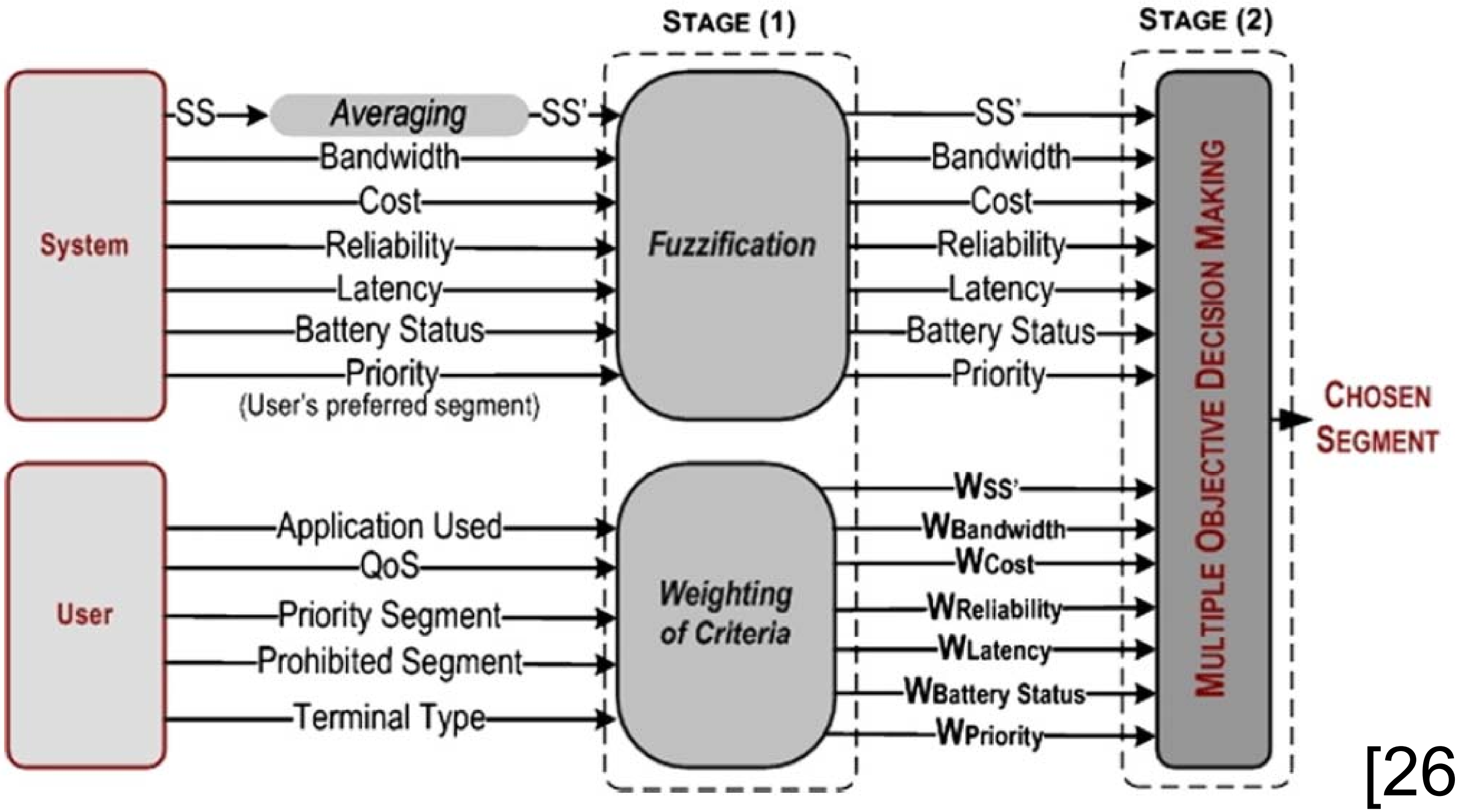
❖Fuzzy logic and neural networks based strategies [19-22]



[22]

Related Work (5/5)

❖Context-aware strategies [23-27]



[26]

Appendix III

Context for Handover Decisions

Context for Handover Decision

❖ User Metrics

- User preferences (preferred cost, bandwidth rate, network type, power consumption , security): QoS, Lifetime, Cost
  - QoS: Bandwidth, Delay, Jitter, BER, Throughput, Burst error, Packet Loss Ratio
  - Lifetime: Tx, Rx, Idle Power consumption of network interface card
  - Cost: different cost model

❖ Application Metrics

- Bandwidth, packet error rate, delay, jitter

❖ Service Classes

- Conversational, streaming, interactive, background

Context for Handover Decision

❖ Network context

- Network cost, coverage, bandwidth, traffic load, jitter, supported classes of service

❖ Link context

- Received signal strength, SNR, SIR and BER

❖ Device capabilities

- Available access networks, current power level (battery level)
- All different network interfaces have their own characteristics
- Available network interfaces are determined by context information (location, velocity, and application)

❖ Mobile node

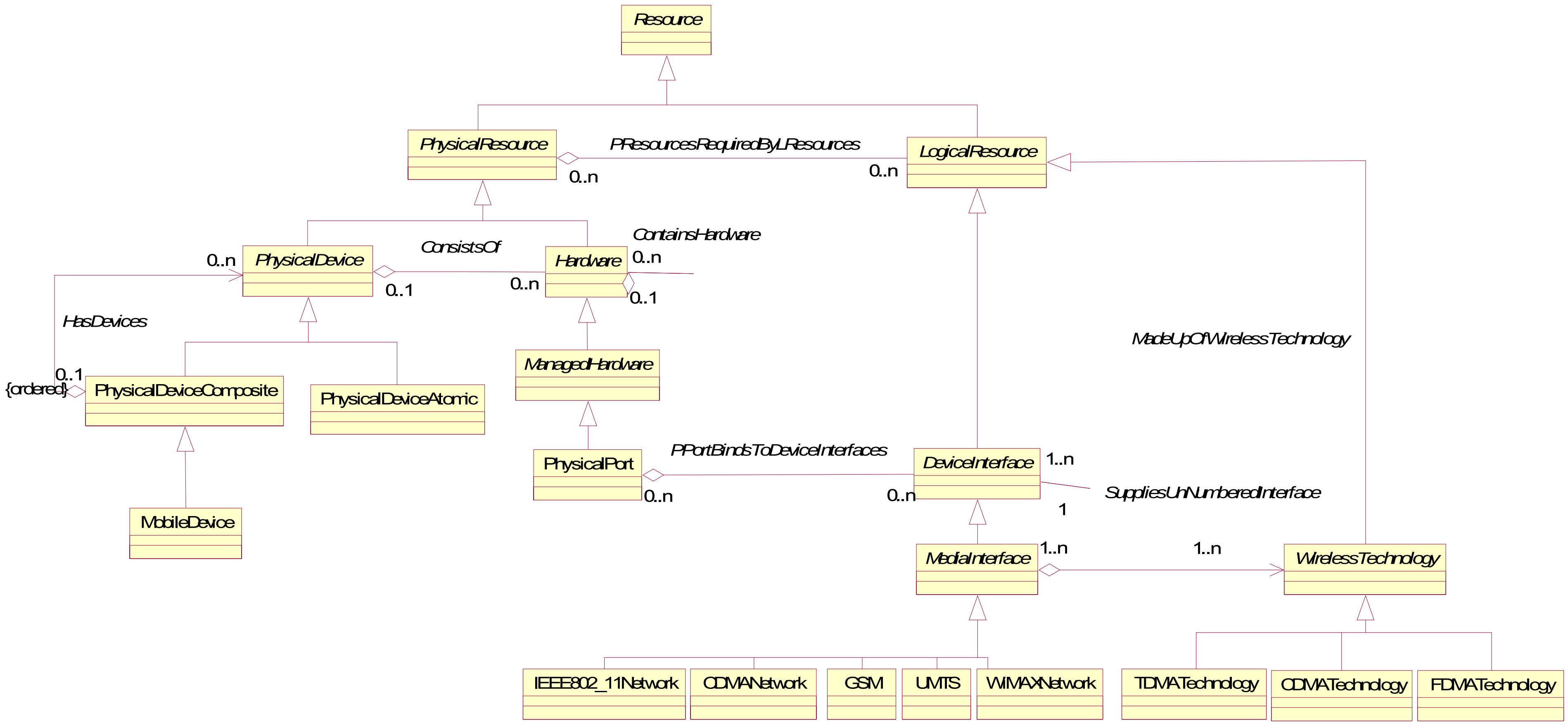
- Location, velocity

Appendix IV

Information Modeling for Handover Decisions

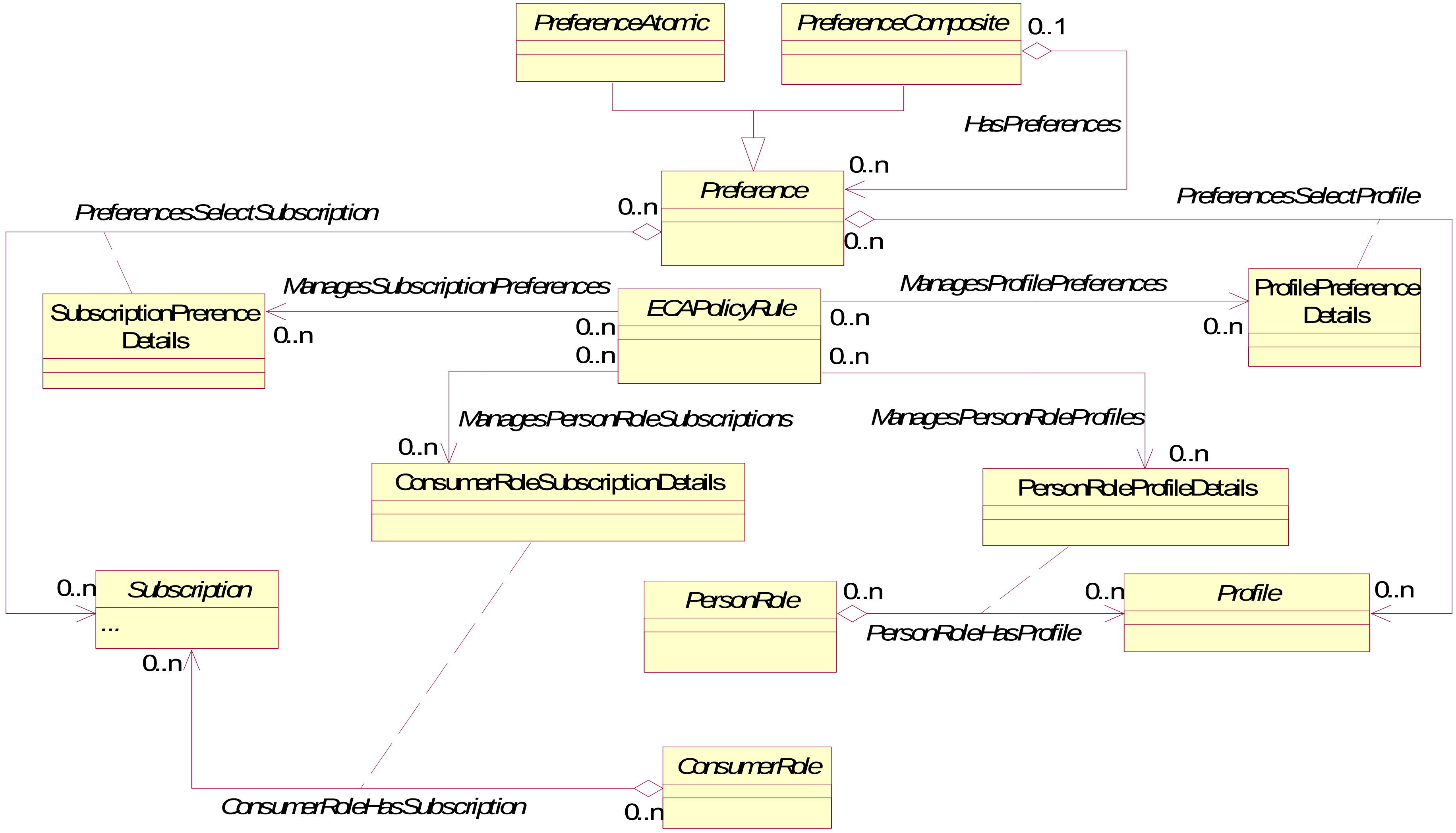
Information Models

❖DEN-ng models for handover decision



Information Models

❖User Profile, Preference, Policy



Appendix V

AUHO Algorithm Pseudocode

Algorithm 1: AUHO decision making process

input : An Network Interface list NI of size n and a current application App
output: The best satisfying NI,bestNI, and the Best satisfying AP,bestAP

```
up ← LoadPolicy(App) ;
bestNI ← null;
bestAP ← null;
for i ← 1 to n do
    if isSpeedSupported(NI[i]) and isSLASupported(NI[i]) then
        if bestNI is equal to null then
            bestNI ← NI[i] ;
        AP ← GetCandidateAPList(NI[i]) ;
        m ← the number of AP ;
        maxAP ← null;
        for j ← 1 to m do
            if maxAP is equal to null then
                maxAP ← AP[j] ;
            else if GetAPSV(maxAP,up) < GetAPSV(AP[j],up) then
                maxAP ← AP[j] ;
        if bestAP is equal to null then
            bestAP ← maxAP ;
        else if GetAPSV(bestAP,up) < GetAPSV(maxAP,up) then
            bestAP ← maxAP ;
            bestNI ← NI[i] ;
currentAP ← GetCurrentAP() ;
currentNI ← GetCurrentNI() ;
if GetAPSV(bestAP,up) − GetAPSV(currentAP,up) ≤ δ then
// threshold for considering handover overheads
    bestAP ← currentAP ;
    bestNI ← currentNI ;
```

Appendix VI

Policy Definition

Policy for Handover Decision

```
rulebase := rule*;
rule := NAME event condition* action;
event := VOICE CALL | STREAMING | FTP | VIDEO CALL |
 WEB BROWSER | SMS;
condition := atom*;
atom := var op value
var := LOCATION | CALLER | TIME | TEMPERATURE
op := = | < | > | <= | => | <>;
value := real context information;
action := method userprofile;
method := RANDOM | RSS | COST | QUALITY | LIFETIME |
AUHO;
userprofile := mode;
mode := ORDINARY userpreference_ordinary |
ADVANCED user_preference_advanced;
user_preference_ordinary := RSS? COST? QUALITY?
LIFETIME?
User_preference_advanced := pref weight;
pref := RSS | COST | QUALITY | LIFETIME;
weight := [0.0 – 1.0];
```

grammar

```
<rulebase>
  <rule>
    <name>voicecall_rule</name><event>Voice Call</event>
    <condition>
      <atom><var>LOCATION</var><op>=</op>  <value>HOME</value>
        <value>OFFICE</value></atom>
    </condition>
    <action>
      <method>AUHO</method>
      <user_profile mode="ordinary">
        <user_preference>Cost</user_preference>
        <user_preference>Quality</user_preference>
      </user_profile>
    </action>
  </rule>
  <rule>
...
    <action>
      <method>AUHO</method>
      <user_profile mode="advanced">
        <user_preference><pref>Cost</pref><weight>0.7</weight>
        </user_preference>
        <user_preference><pref>Quality</pref><weight>0.3</weight>
        </user_preference>
      </user_profile>
    </action>
  </rule>
...
</rulebase>
```

Example (XML)

User Profile Settings

❖User profile settings mode

- Ordinary user: pre-defined Ups
- Advanced user: manual setting mode

- Examples of pre-defined UP

User preference	RSS	Cost	Quality	Lifetime	RSS & Cost	Cost & Quality		Cost & Quality & Lifetime	RSS & Cost & Quality & Lifetime
W_{RSS}	0.7	0.1	0.1	0.1	0.4	0.1	…	0.1	0.25
W_{Cost}	0.1	0.7	0.1	0.1	0.4	0.4		0.3	0.25
$W_{Quality}$	0.1	0.1	0.7	0.1	0.1	0.4		0.3	0.25
$W_{Lifetime}$	0.1	0.1	0.1	0.7	0.1	0.1		0.3	0.25

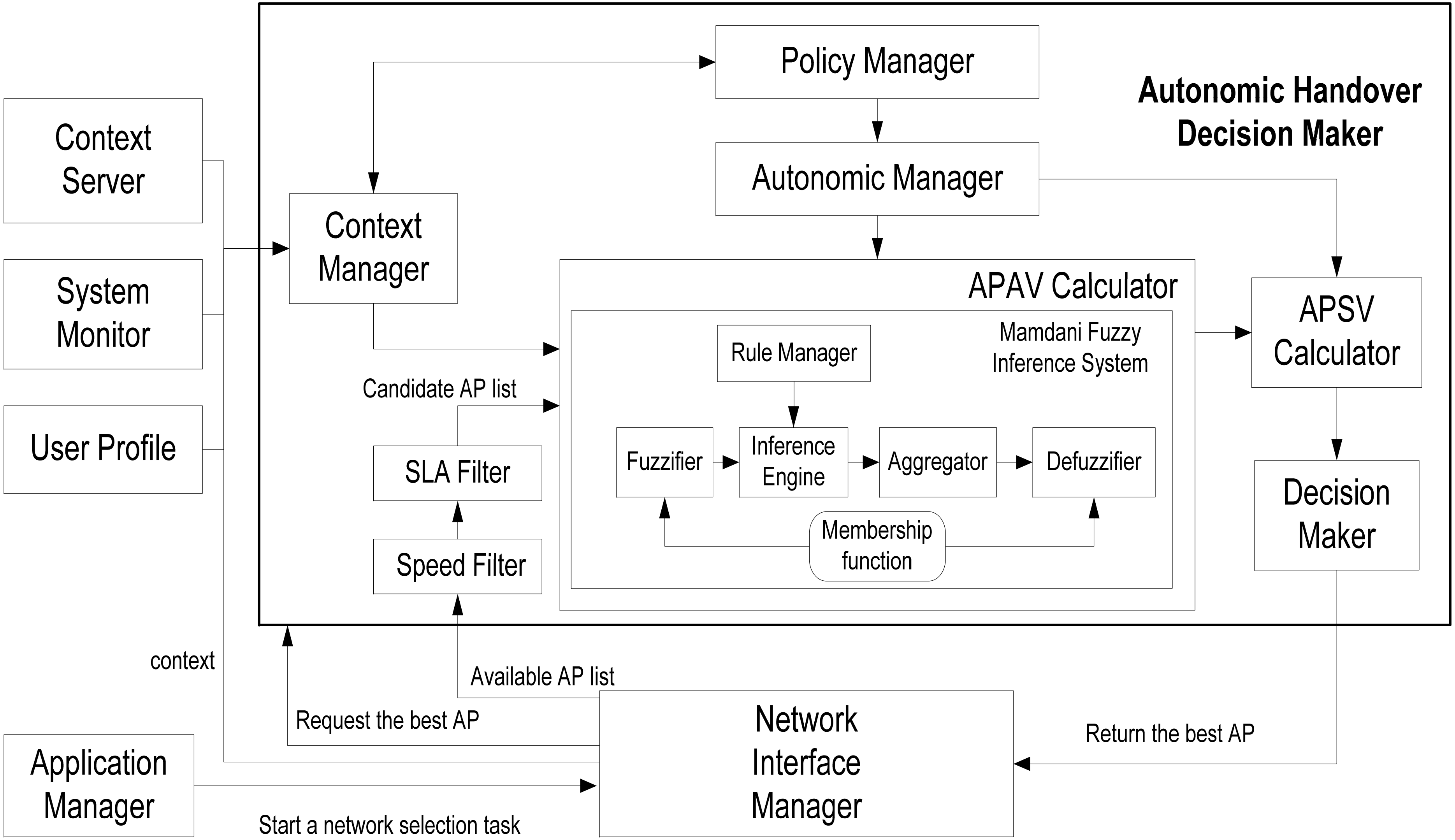
User Profiling

- **User profiling is typically either knowledge- or behavior-based**
  - The former creates static models of users and dynamically match users to the closest model
  - The latter uses the user's behavior as a model, typically using machine-learning techniques to discover useful patterns in the behavior
    - Typically, this is a two-class model (e.g., like | dislike)
- **Knowledge must be acquired in order to create the user profile**
  - Explicit knowledge is preferred, since it can supply more detailed and useful data, but it has the drawback of interrupting the user
    - Implicit knowledge acquisition is often preferred, since it has little or no impact on the user's normal activity
    - Data is discovered over a period of time; when "complete enough", it is used to infer preferences
  - Model is then refined by monitoring subsequent behavior
- **Typically, user profiles are organized as either**
  - Systems that store every user's ratings on available items so correlation techniques can be used to find similar users, or
  - Systems that store representations of specific items of interest to a single user so machine-learning techniques can find similar items

Appendix VII

AUHO System Architecture

System Architecture



Appendix VIII

APAV Calculation Details

APAV and APSV

❖ APAV

- *Suitability* of a particular AP to provide services for an end user based on a given set of user preferences (e.g. RSS, Quality, Cost, and Lifetime) [0.0, 1.0]
- APAVs are not absolute but relative values
- If the APAV of AP_1 is greater than that of AP_2 in terms of the specific Upref, AP_1 is better than AP2 for selecting the optimal AP
- Ex. If $APAV_{Quality}$ of AP_1 is 0.7 and $APAV_{Quality}$ of AP_2 is 0.4, AP_1 is accepted for user preference Quality

❖ APSV

- How well a particular AP satisfies the needs of the en d user based on his or her user profile
- APSVs are not absolute but relative values
- If the APSV of AP_2 is greater than that of AP_2 in terms of an user's UP, AP_1 is preferred than AP_2 (higher user satisfaction)

Fuzzy Logic

❖ Fuzzy logic:

- A way to represent variation or imprecision in logic
- A way to make use of natural language in logic
- Approximate reasoning

❖ Humans say things like "If it is sunny and warm today, I will drive fast"

❖ Linguistic variables:

- Temp: {freezing, cool, warm, hot}
- Cloud Cover: {overcast, partly cloudy, sunny}
- Speed: {slow, fast}

L. Zadah, "Fuzzy sets as a basis of possibility" Fuzzy Sets Systems, Vol. 1, pp3-28, 1978.

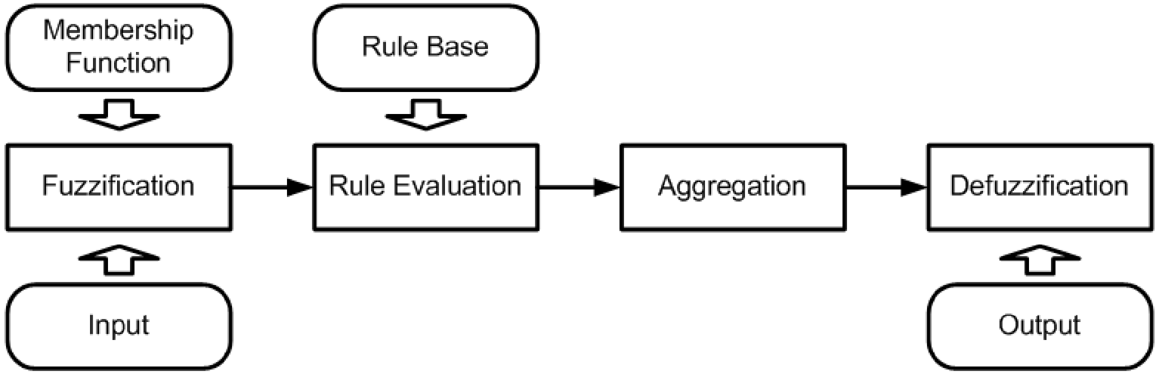
Mamdani Fuzzy Inference

❖ The most commonly used fuzzy inference technique is the so-called Mamdani method.

❖ In 1975, Professor Ebrahim Mamdani of London University built one of the first fuzzy systems to control a steam engine and boiler combination. He applied a set of fuzzy rules supplied by experienced human operators.

❖ The Mamdani-style fuzzy inference process is performed in four steps:

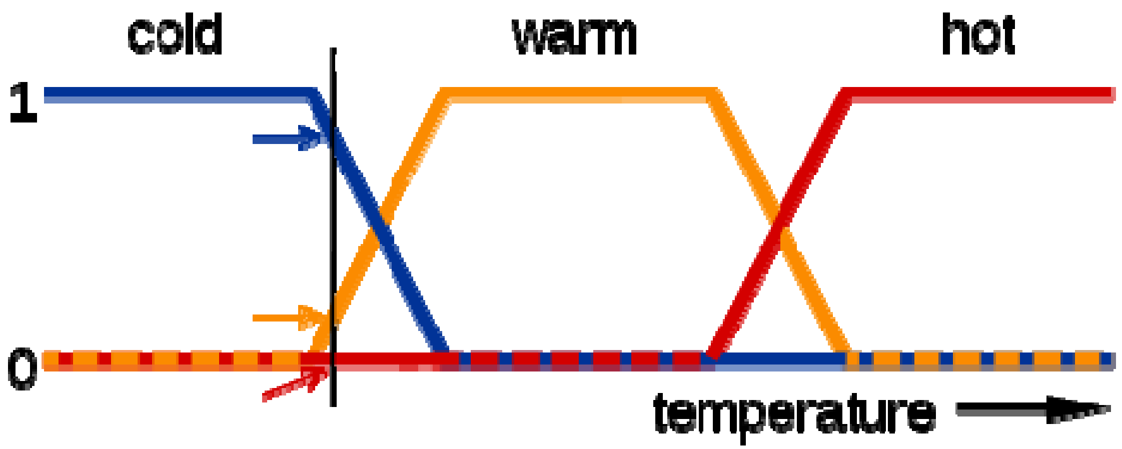
1. Fuzzification of the input variables
2. Rule evaluation (inference)
3. Aggregation of the rule outputs (composition)
4. Defuzzification.



Mamdani Fuzzy Inference

❖Rule

- IF temperature IS very cold THEN stop fan
- IF temperature IS cold THEN turn down fan
- IF temperature IS warm THEN maintain level
- IF temperature IS hot THEN speed up fan



APAV Calculation

❖ Method

- We calculate an APAV using fuzzy logic, which provides the ability to use data values that can have a specific range of values that are resolved at runtime

❖ Four APAVs according to User Preferences

- RSS: $APAV_R$
- Cost: $APAV_C$
- Quality: $APAV_Q$
- Lifetime: $APAV_L$

APAV Calculation

❖ APAV of RSS: $APAV_R$

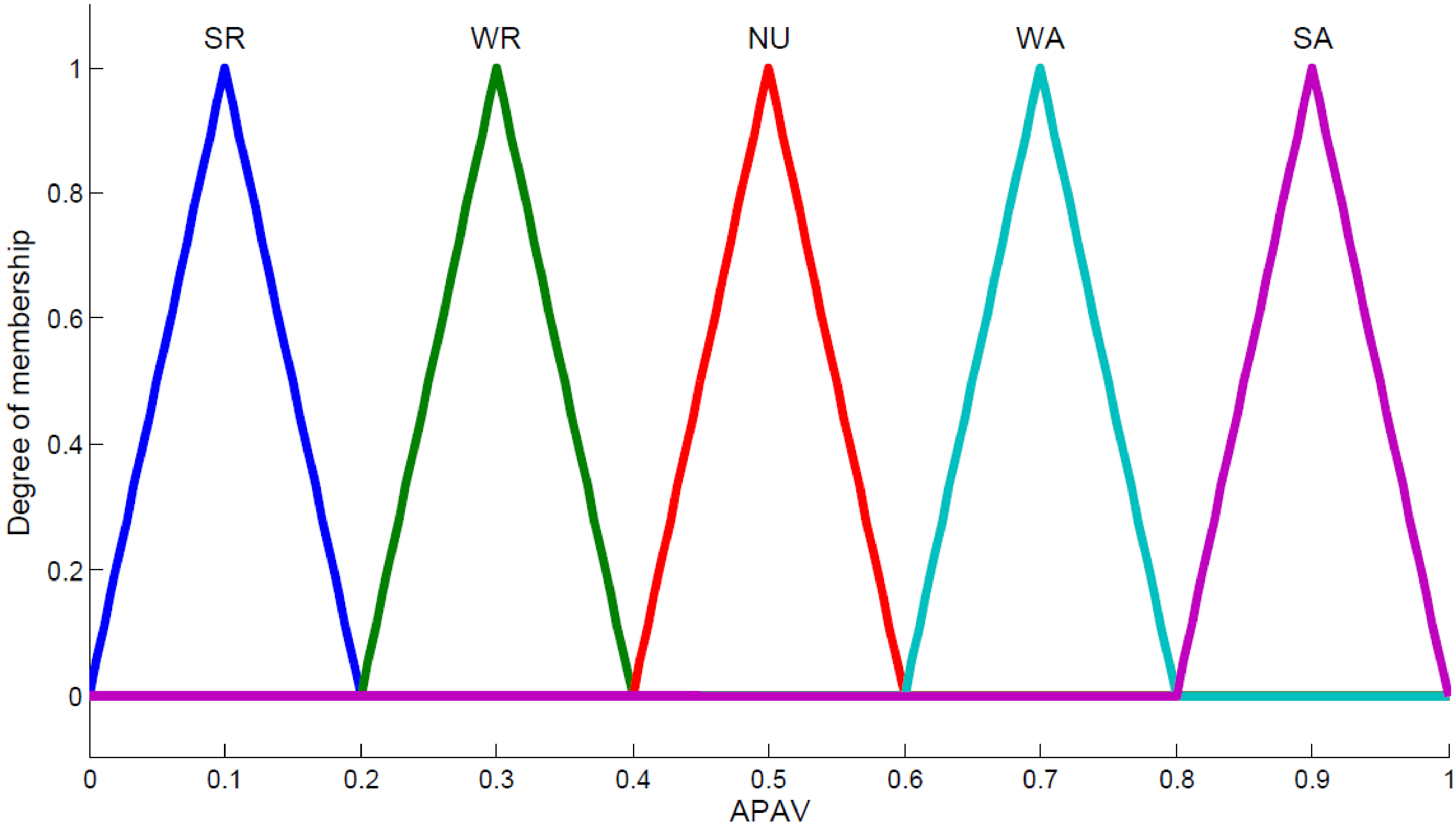
- Calculated using Received Signal strength Indicator (RSSI)
- Normalize the value range from 0 to 1
- High RSSI is high $APAV_R$

❖ APAV of Cost: $APAV_C$

- $/min, $/bytes, or a flat-rate charge
- Normalize the value range from 0 to 1
- High cost rate is low $APAV_C$

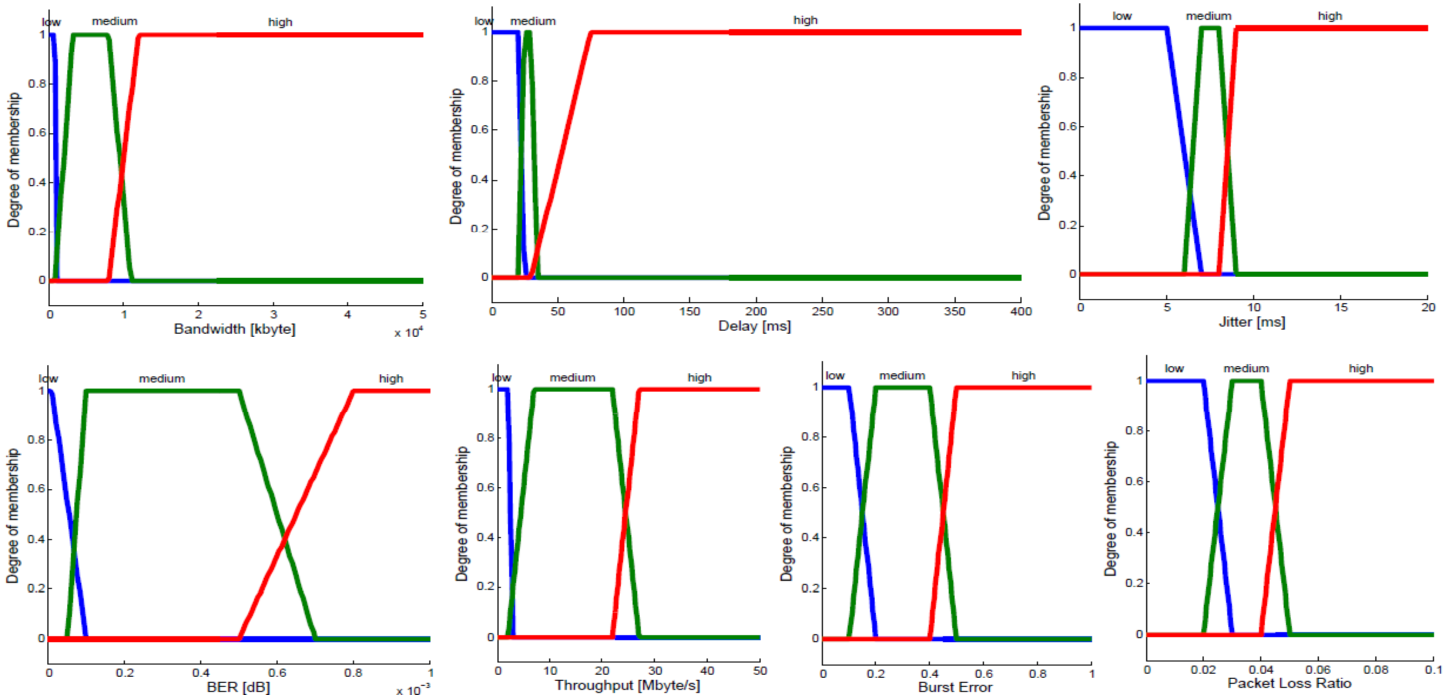
APAV Calculation

❖Fuzzy membership functions (Output)



❖APAV of Quality: $APAV_Q$

- Define 7 input metrics and 7 input membership functions: Delay, Jitter, Bandwidth, BER, Throughput, BurstError, PLR
- Define different fuzzy rule sets for each application type because each application requires different parameters to evaluate quality
- Input fuzzy membership functions



APAV Calculation

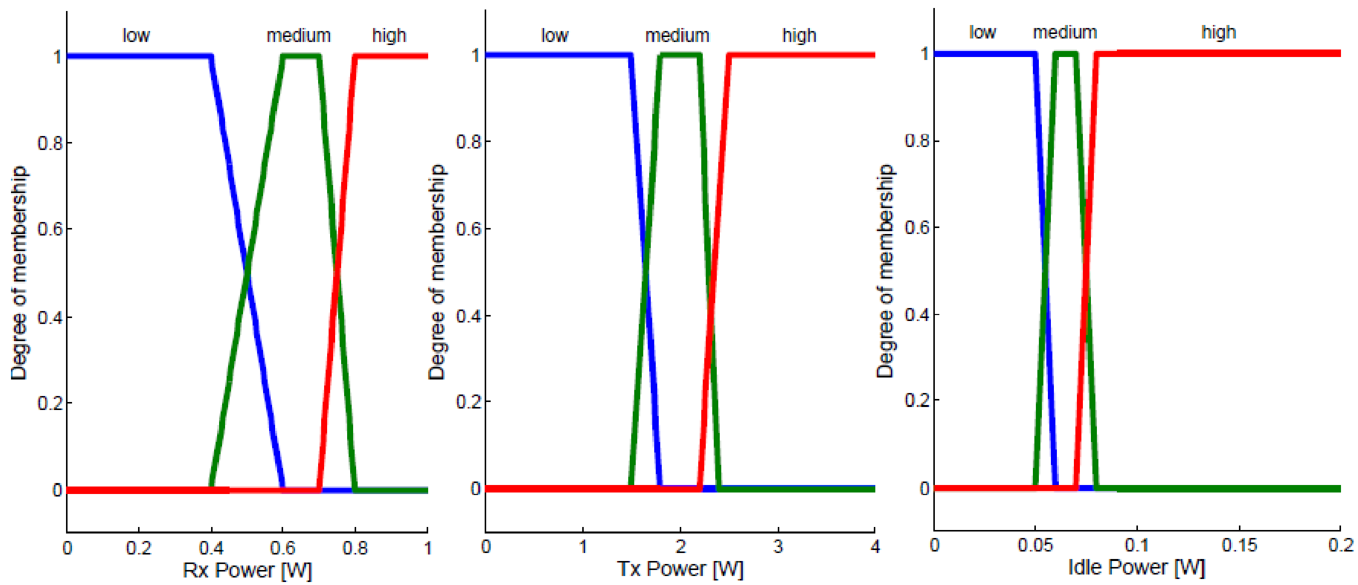
- **Three different types of applications were used**
  - Voice call, streaming multimedia, and FTP
- **Example of $APAV_Q$**
  - Voice call: delay and jitter are important factors
  - Fuzzy rule definition

RULE 1 : IF delay IS low	AND jitter IS low	THEN APAV IS SA;
RULE 2 : IF delay IS low	AND jitter IS medium	THEN APAV IS WA;
RULE 3 : IF delay IS low	AND jitter IS high	THEN APAV IS NU;
RULE 4 : IF delay IS medium	AND jitter IS low	THEN APAV IS WA;
RULE 5 : IF delay IS medium	AND jitter IS medium	THEN APAV IS NU;
RULE 6 : IF delay IS medium	AND jitter IS high	THEN APAV IS WR;
RULE 7 : IF delay IS high	AND jitter IS low	THEN APAV IS NU;
RULE 8 : IF delay IS high	AND jitter IS medium	THEN APAV IS WR;
RULE 9 : IF delay IS high	AND jitter IS high	THEN APAV IS SR;

APAV Calculation

❖ APAV of Lifetime: $APAV_L$

- Define 3 input metrics and 3 input membership functions: Tx, Rx, Idle power
- Define different fuzzy rule sets for each application type because each application requires different parameters to measure power consumption
- Input fuzzy membership functions



APAV Calculation

❖ Power consumption

$$PowerConsumption(Application) = W_{Tx} * Power(Tx) + W_{Rx} * Power(Rx) + W_{Idle} * Power(Idle)$$

❖ Three different types of applications were used

- Voice call, streaming multimedia, and FTP

❖ **Example of APAV$_L$**

- Voice call: Tx and Rx power consumption is important factors
- Fuzzy rule definition

RULE 1 :	IF tx IS low	AND rx IS low	AND idle IS low	THEN APAV IS SA;
RULE 2 :	IF tx IS low	AND rx IS low	AND idle IS medium	THEN APAV IS SA;
RULE 3 :	IF tx IS low	AND rx IS low	AND idle IS high	THEN APAV IS WA;
		...		
RULE 25 :	IF tx IS high	AND rx IS high	AND idle IS low	THEN APAV IS SR;
RULE 26 :	IF tx IS high	AND rx IS high	AND idle IS medium	THEN APAV IS SR;
RULE 27 :	IF tx IS high	AND rx IS high	AND idle IS high	THEN APAV IS SR;

APSV Calculation

❖ Definition

- How well a particular AP *satisfies* the needs of the end user based on his or her user profile [0.0, 1.0]

❖ Method

- We calculate an APSV using utility theory, which is widely used in economics for representing the ability of goods or services to satisfy human needs
- Utility: a measure of relative satisfaction
- Utility function

$$U(\vec{w}, \vec{x})$$

  - $\vec{x}$ a set of observed product criteria
  - $\vec{w}$ user preferences into a real number

APSV Calculation

❖ Additive aggregate utility function

- Aggregate multi criteria utility of an access network

$$U(\mathbf{x}) = \sum_{i=1}^{n} w_i u_i(X_i) \quad where \sum_{i=1}^{n} w_i = 1$$

  - x : the vector of n criteria
  - w_i : user preference (RSS, Cost, Quality, Lifetime)
  - u_i : APAV ($APAV_R$, $APAV_C$, $APAV_Q$, $APAV_L$)
  - X_i : candidate AP
- Easy and comprehensible approach
- Widely used in utility theory based approaches

APSV Calculation

❖ APAVs for all candidate APs

$$\overrightarrow{APAV(AP_{i,j})} = (APAV_R(AP_{i,j}) \quad APAV_C(AP_{i,j}) \quad APAV_Q(AP_{i,j}) \quad APAV_L(AP_{i,j}))$$

- $AP_{i,j}$: denotes the j[th] access point of the i[th] access network

❖ Applying a utility function for APSV (Additive aggregate utility)

$$APSV(AP_{i,j}) = \overrightarrow{UP} \bullet \overrightarrow{APAV(AP_{i,j})}^T$$

$$= (W_R \quad W_C \quad W_Q \quad W_L)\begin{pmatrix} APAV_R(AP_{i,j}) \\ APAV_C(AP_{i,j}) \\ APAV_Q(AP_{i,j} \\ APAV_L(AP_{i,j}) \end{pmatrix}$$

$$= W_R \cdot APAV_R(AP_{i,j}) + W_C \cdot APAV_C(AP_{i,j}) + W_Q \cdot APAV_Q(AP_{i,j})$$
$$+ W_L \cdot APAV_L(AP_{i,j})$$

❖ Output

- Select the most satisfying AP for the current application
- Maximum APSV is the best satisfying AP for end user

Appendix IX

HMNToolSuite Details

HMNToolSuite

❖Why new simulator?

- Existing network simulators focus on L2 handover protocols, our network simulator focus on L7
- We focus on higher-level aspects of the handover decisions
  - How to use context information
  - Policies to govern handover decisions
- There is a need for a more flexible and user-friendly simulation tool
- Anyone can test handover decision making algorithms (or other algorithms) in heterogeneous wireless networks

HMNToolSuite

❖ Validation of our Simulator

Existing network simulator	HMNToolSuite
L2 handover protocol	L7 handover decision
Backend simulator	Frontend simulator
Network traffic, mobile node, MAC	Mobility, mobile device, policy
Detail protocol implementation	Policy-based management

- Our HMNToolSuite is not separate to other network simulators, it can use network traffic traces from the existing network simulators
- We tested the previous handover decision algorithms on the HMNToolSuite and we can trust it due to same results
- Our simulator focuses on L7 mobility. We used other L2 handover protocols from ns-2 which has well-validated protocol models
- We used the Free Space Path Loss Model for wireless transmission media because it is the most common model where the received signal strength is computed assuming a perfect obstacle free environment, where transmission losses due to multipath fading, shadowing, etc. are ignored.
- It can be easily extended with different signal modeling. The current version of our simulator has some limitations for applying real wireless communication environments

Appendix X

Experiment Details

Network Device Parameters

Access Network (Access Point)	CDMA (BS1)	CDMA (BS2)	CDMA (BS3)	WLAN (AP1)	WLAN (AP2)	WLAN (AP3)	WiBro (RAS1)
Coverage (meter)	1000	1000	1000	400	400	400	800
Bandwidth (kbyte)	1000	1000	1000	11000	11000	11000	2000
Delay (ms)	25	19	22	8	25	45	25
Jitter (ms)	7	6	7	4	8	10	8
Bit Error Ratio (dB)	0.001	0.001	0.001	0.00001	0.00001	0.00001	0.0001
Throughput (Mbyte/s)	1.3	1.7	1.7	25	25	25	15
Burst Error	0.6	0.5	0.5	0.2	0.2	0.2	0.1
Packet Loss Ratio	0.08	0.07	0.07	0.04	0.04	0.04	0.02
Cost Rate ($/min)	0.9	0.9	0.9	0.2	0.2	0.2	0.5
Power Tx (W)	1.4	1.4	1.4	2.8	2.8	2.8	2
Power Rx (W)	0.925	0.925	0.925	0.495	0.495	0.495	0.7
Power Idle (W)	0.045	0.045	0.045	0.082	0.082	0.082	0.06
Minimum Speed (km/h)	0	0	0	0	0	0	0
Maximum Speed (km/h)	300	300	300	12	12	12	80

Experimental Setup

- **Location 1**
  - Starting point
- **Location 2**
  - The delay and jitter of BS1 are higher than those of BS2, and the speed of the MN1 is changed to 10 km/h
- **Location 3**
  - The power consumption rate of CDMA is lower than that of WLAN
- **Location 4**
  - The quality of WLAN is lower than that of CDMA. However the price of WLAN is lower than that of CDMA
- **Location 5**
  - The speed of MN1 is changed to 40 km/h. WLAN is filtered by the speed filter
  - The quality of BS2 is higher than that of BS3
- **Location 6**
  - The price of WiBro is lower than that of CDMA

Experiment Result

- **If your decision algorithm selects the different AP compared to other previous decision algorithms, is there any problem?**
  - In terms of functional requirements, our proposed algorithm did not provide a good solution for handover decisions compared to other decision algorithms.
  - However, we focused on end user satisfaction based on both functional and non-functional requirements
  - We also considered a threshold for handover overhead to overcome degradation of performance.
  - As future work, we will show that the degradation of performance is reasonable in terms of end user satisfaction

Appendix XI

Future Work Details

Future Work

- **Fuzzy logic optimization for calculating APAVs**
  - We will apply an Ant Colony Optimization algorithm
- **Optimization of weight values for building user profiles**
  - We will apply a genetic algorithms
- **Improvement of utility function for calculating APSVs**
  - We will apply a multiplicative utility function or other utility function to overcome the limitations
- **Complete autonomic decision architecture**
  - We will apply ontology and semantic reasoning to infer new data and facts that can be used to fine-tune our decision algorithms

Ant Colony Optimization

❖Publication

- C.-F. Juang and P.-H. Chang, "Designing fuzzy-rule-based systems using continuous ant-colony optimization," IEEE Transactions on Fuzzy Systems, vol. 18, no. 1, pp. 138–149, Feb. 2010.
- Rule generation
  - Generates fuzzy rules online upon receiving training data
  - Initial path and solution construction
  - New solution generation
  - Ant path construction

Genetic Algorithm

❖ Publications

- Kalyanomoy Deb, Amrit Pratap, Sameer Agarwal, T. Meyarivan, “A Fast Elitist Multi-Objective Genetic Algorithm: NSGA-II,” IEEE Transactions on Evolutionary Computation, vol. 6, 2000, pp. 182-197
- M. Alkhawlani and A. Ayesh, "Access Network Selection Based on Fuzzy Logic and Genetic Algorithms," Advances in Artificial Intelligence, vol. 2008, pp. 1-12.
- Andres J. Ramirez , David B. Knoester , Betty H.C. Cheng , Philip K. McKinley, "Applying genetic algorithms to decision making in autonomic computing systems," Proceedings of the 6th International Conference on Autonomic Computing, June 15-19, 2009, Barcelona, Spain.

Utility function

- **Additive utility function has some serious limitations**
  - Whether the multi-criteria utility function can be separated into independent parts where u_i, the utility of criterion i, does not dependent on the value of other criteria
  - If it can indeed be separated, the elementary utility $u_i(x_i)$ can simply be added to produce the aggregate utility
  - If they are not independent, we will apply a multiplicative utility function presented in [93]

*[93] Q.T. Nguyen-Vuong, Y. Ghamri-Doudane, and N. Agoulmine. **On utility models for access network selection in wireless heterogeneous networks**. In Network Operations and Management Symposium, 2008. NOMS 2008. IEEE, pages 144-151. IEEE, 2008.*

Novel Approach?

- Proved from our patents
  - 5 patents (2 KR, 1 EPO, 1 JP, and 1 US)
    - 2 Registered (KR, JP)
    - 1 will be registered soon (US)
- Functional and Non-functional requirements
- Different evaluation method as application types
- End user satisfaction based on user preference and profile
- Decision for both horizontal and vertical handover
- Scalability and flexibility
- L7 handover decision
- Easy to generalize due to technology-neutral approaches

Integration with Real System

❖Assumptions

- Difficult to deploy the unified OSS (Operations Supported System) to gather all available context information due to the federation problems in network operators and service providers.

❖Solution

- However, if these problems will be solved, our approach will be directly applied to handover decisions for personalized services.

Practical Aspect

- Our approach can apply the current mobile device in heterogeneous wireless networks operated by one network operators (KT, SKT or LGT)
- In the future, if the federation problem will be solved among network operators, our approach is easy to apply
- Handover overhead is a big problem, but L2 handover should be optimized for reducing overhead
- We have discussed with engineers from KT, SKT, LGT, and Samsung