國立臺北大學
資訊工程學系
Department of Computer Science and Information Engineering,

Chapter 7:
A Hybrid Spectrum Mobility and Handover Protocol in 3GPP Cognitive LTE Systems

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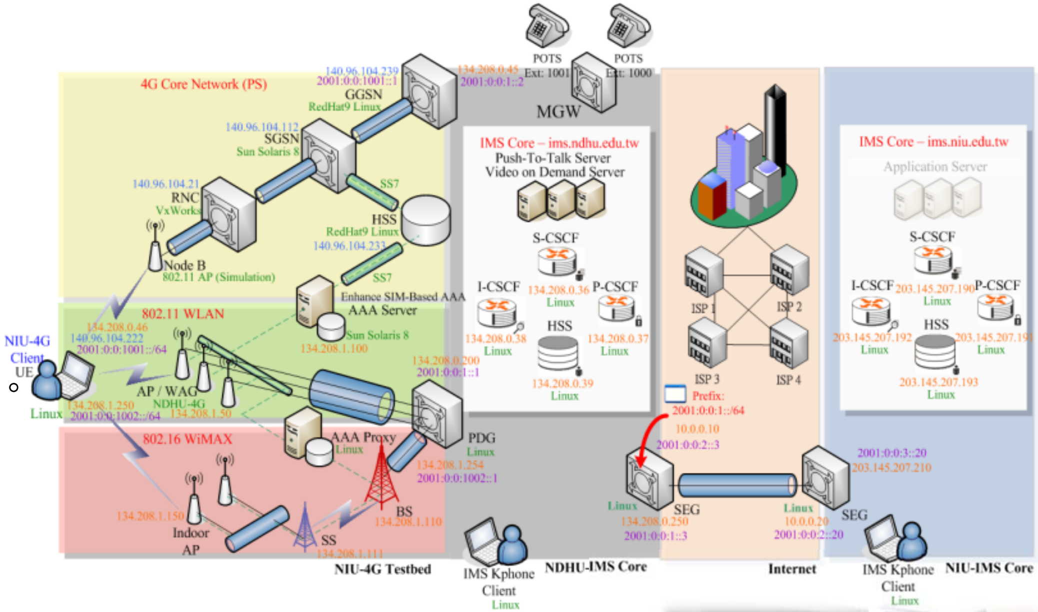
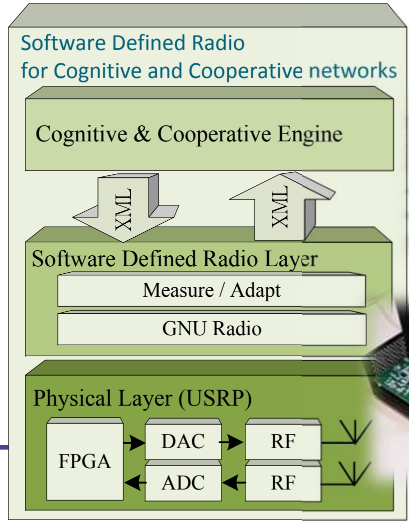
Outline

- Abstract
- Introduction
- Related works
- Motivation and basic idea
- Our proposed protocol
- Performance analysis and simulation results
- A system demo
- Conclusion and on-going works

電信國家型計畫：跨層式感知與協力4G-IMS無線網路研究（98~100 年）

- ■執行單位：國立宜蘭大學資訊工程研究所
- ■計畫主持人：趙涵捷教授（校長）
- ■計畫目標
  - □基於第四代行動通訊及IMS核心網路基礎融入感知網路、協力網路與跨層式設計等新穎技術於計畫之4G-IMS無線平台。
- ■計畫成果
  - □建構支援IPv6之Inter-Domain 4G-IMS 無線網路測試平台。
  - □建置VoIP、PoC、VoD、IPTV、IMP、LBS等IMS多媒體應用服務。
  - □建置軟體定義無線電基礎實驗平台。
  - □分別由各團隊針對Security 、QoS 、Mobility等議題進行架構設計。





子計畫四：跨層式感知與協力4G-IMS無線網路之行動管理與媒體存取協定研究

100 年網路通訊國家型科技計畫期中評鑑會議「跨層式感知與協力4G-IMS 無線網路研究」獲頒「**成效卓著**」獎項

1. Abstract

- "**To consume only when necessary**" (spectrum, energy, hardware) is the key issue for the "**Green Communication**".
  - The whole world of telecommunications and information communities is facing a more and more serious challenge.
  - One side the transmitted **multimedia-rich data** are exploding at an astonishing speed and on the other side the total energy consumption by the communication and networking devices and the relevant global **CO2** emission are terribly increasing.
- CR (also called *smart radio) is defined as a wireless* radio device that can **adapt to its operating environment** via **sensing in order to facilitate efficient communications**.
  - The emerging *Cognitive Radio* (CR) system and technology are potentially capable of contributing to solve the abovementioned problem for realizing "**Green Communications**".

1. Abstract

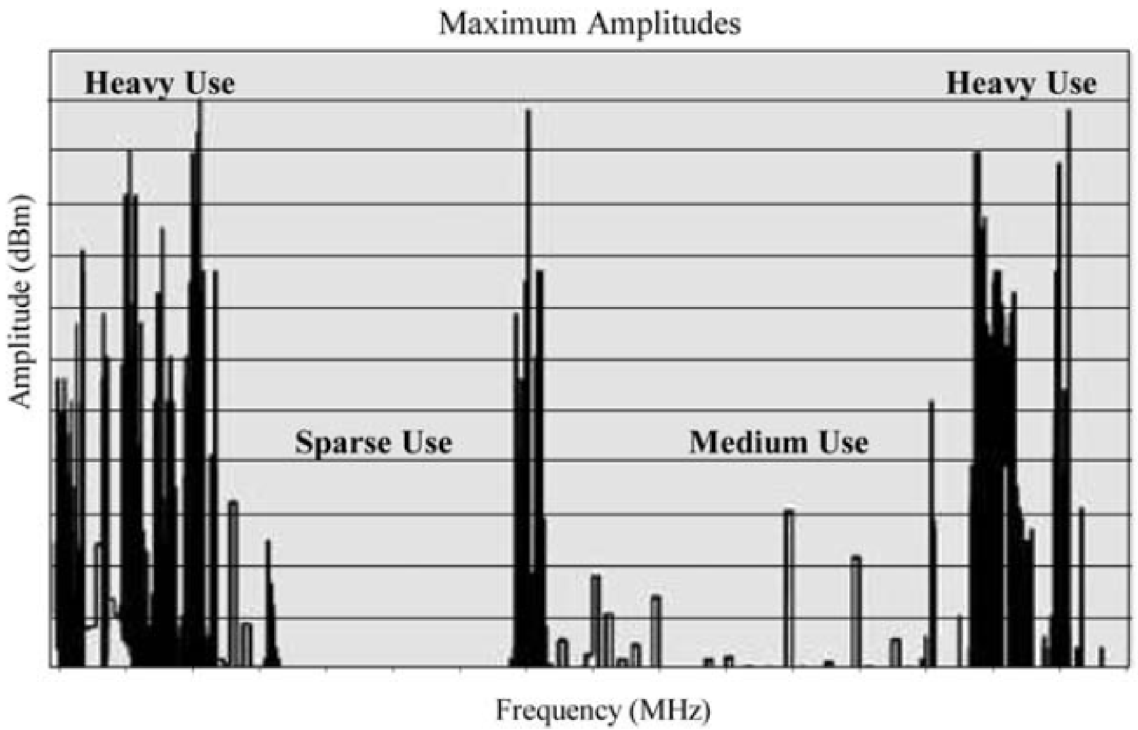
- While the use of **information and communications technology** (**ICT**) is considered to be a facilitator for global energy savings (**teleworking**, **smart logistics**, **smart buildings**, etc.), the volume of network traffic will also increase.
- It was estimated that 3 percent of worldwide energy consumption was caused by the ICT infrastructure that generated about 2 percent of the worldwide CO_2 emissions.
- **Cognitive radio (CR)** is a promising paradigm proposed to be a possible solution of **Green ICT**.
- This talk introduces a **cross-layer** protocol of spectrum mobility (**layer-2**) and handover (**layer-3**) in **cognitive** LTE networks.

2. Introduction

- **Wastage of spectrum resources**
  - While some of the spectrum bands (unlicensed band) have been increasingly usage, most of the other spectrum resources (licensed band) are underutilized.
- **Wireless network bandwidth constraints**
  - It can not fully take advantage of all of the radio spectrum resources for mobile devices and power supply can not continue to use, and the free and unutilized radio spectrum resources is very frequent to lead the low utilization of the radio spectrum.

Low spectrum utilization

- **Spectrum utilization**
  - According to Federal Communications Commission (FCC) , temporal and geographical variations in the utilization of the assigned spectrum range from 15% to 85%

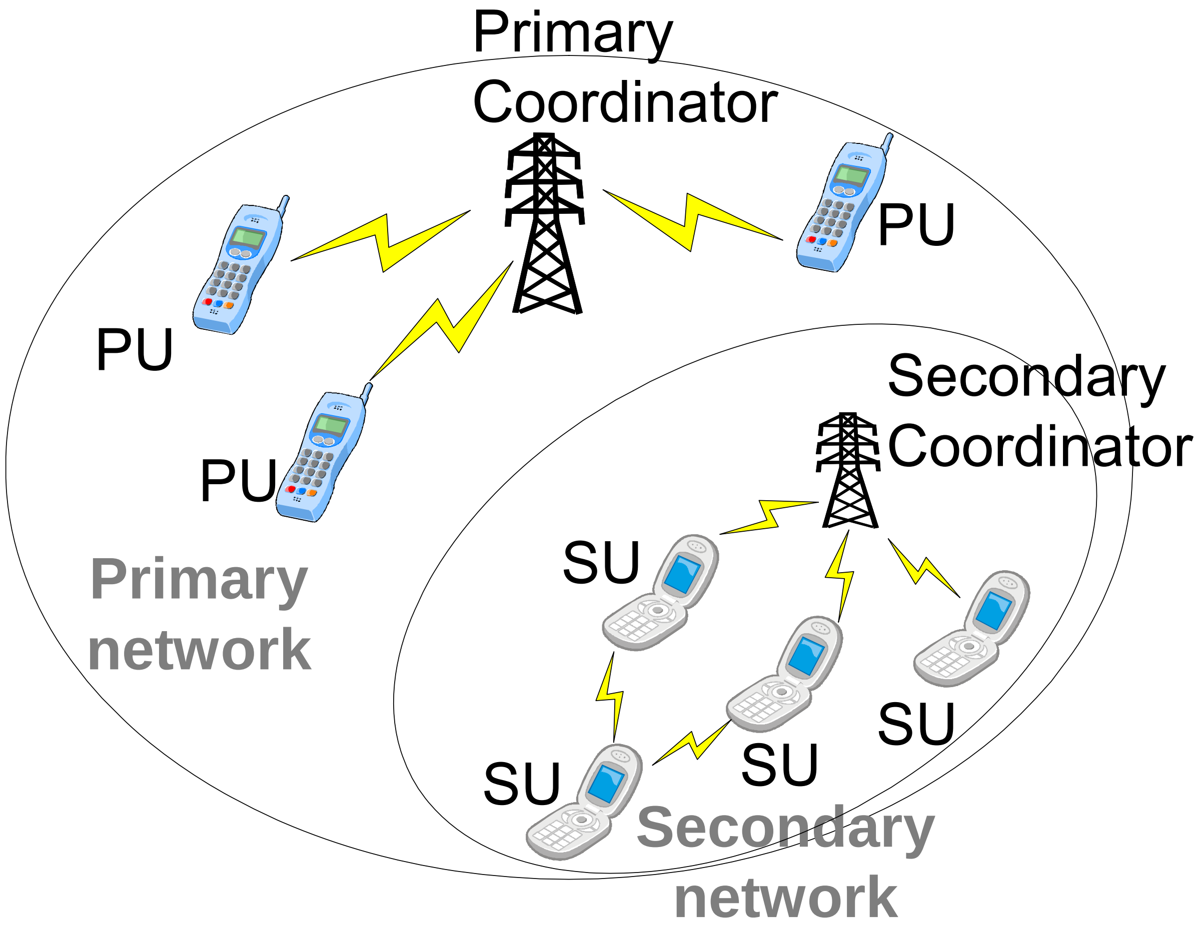


References: FCC. "ET Docket No 03-237 Notice of inquiry and notice of proposed Rulemaking". November 2003.

The cognitive radio (CR)

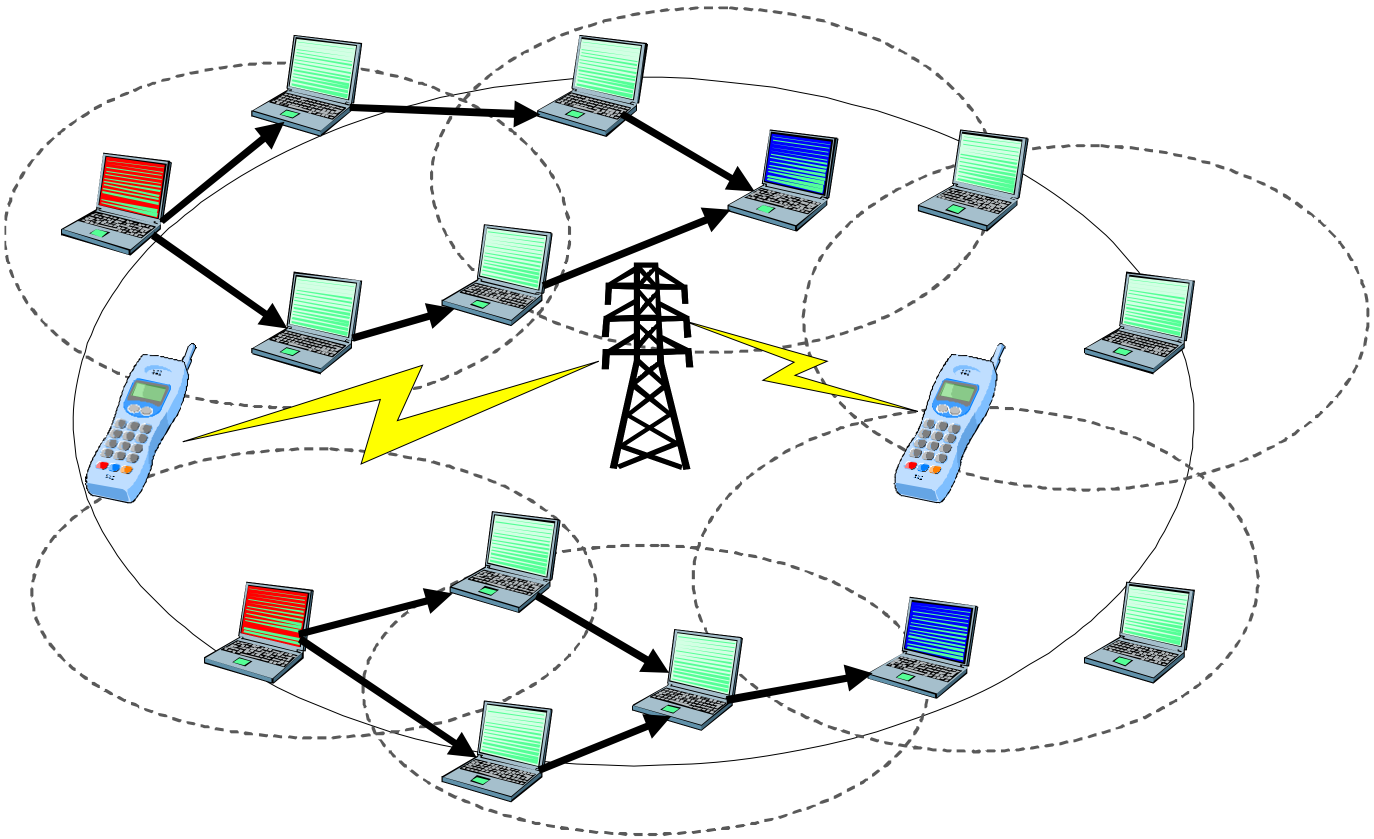
- **Dynamic spectrum access**
  - Allow unlicensed users equipped with cognitive radios to **opportunistically access** the spectrum not used by licensed users.
- In CR networks, there are two types of users; one is **licensed user** (primary user or PU), and the another is **unlicensed user** (secondary user or SU).
  - PUs can access the wireless network resources anytime and anywhere.
  - SUs equipped with **cognitive radios** to opportunistically access the spectrum not used by PUs.
  - When a PU reclaims the radio spectrum resources, the SU detects the reclamation (**spectrum sensing**) and immediately moves away the current radio spectrum resources (**spectrum analysis and decision**) and switch to idle radio spectrum resources (**spectrum mobility**).

Cognitive **Mobile** Networks



Li-Chun Wang, Chung-Wei Wang, and Fumiyuki Adachi, "Load Balancing Spectrum Decision for Cognitive Radio Networks," IEEE JSAC, 2010.

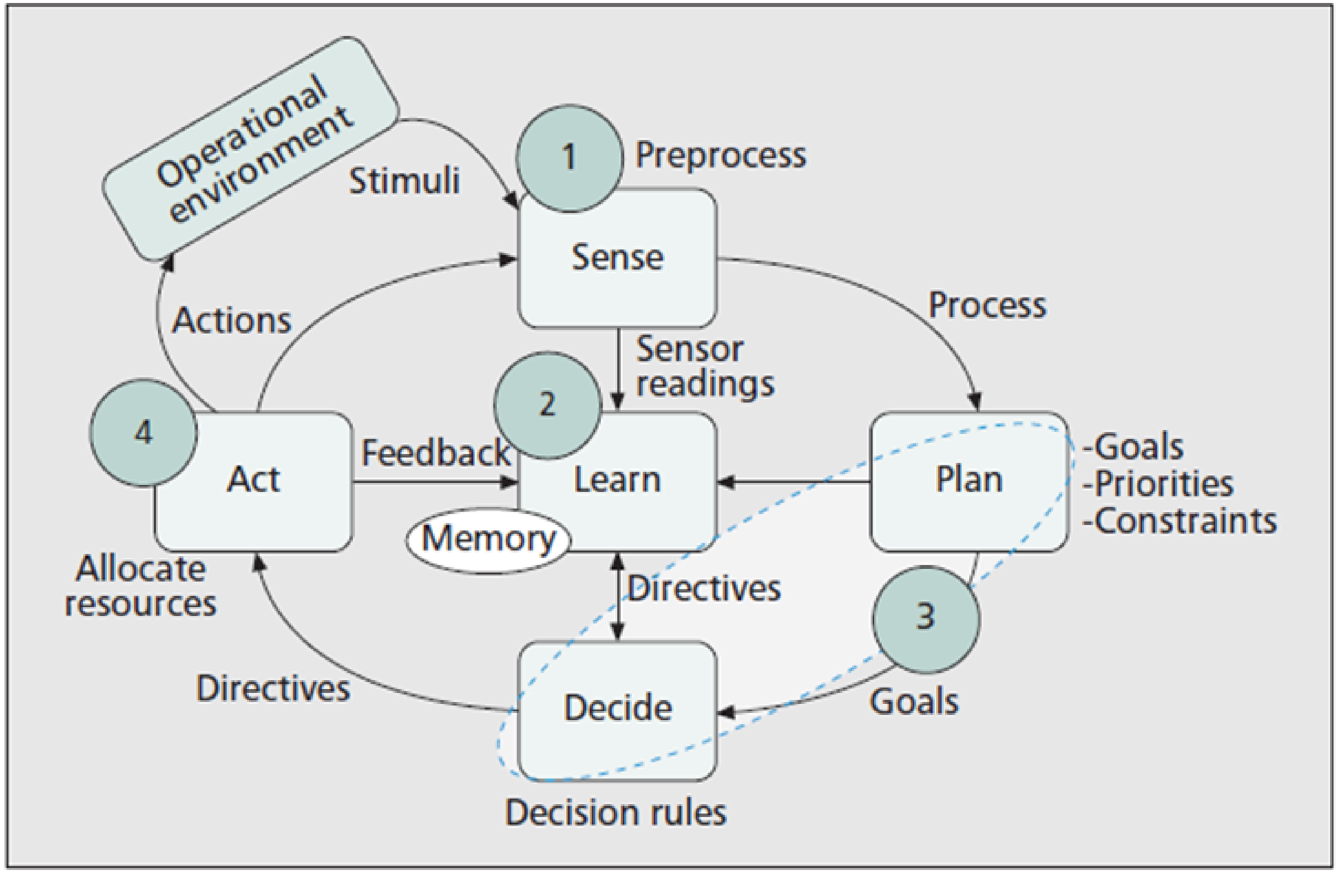
Cognitive **Ad Hoc** Networks



C.F. Shih and **W.J Liao**, "Exploiting route robustness in joint routing and spectrum allocation in multi-hop cognitive radio networks," **IEEE Wireless Communications and Networking Conference** (WCNC 2010), April. 2010.

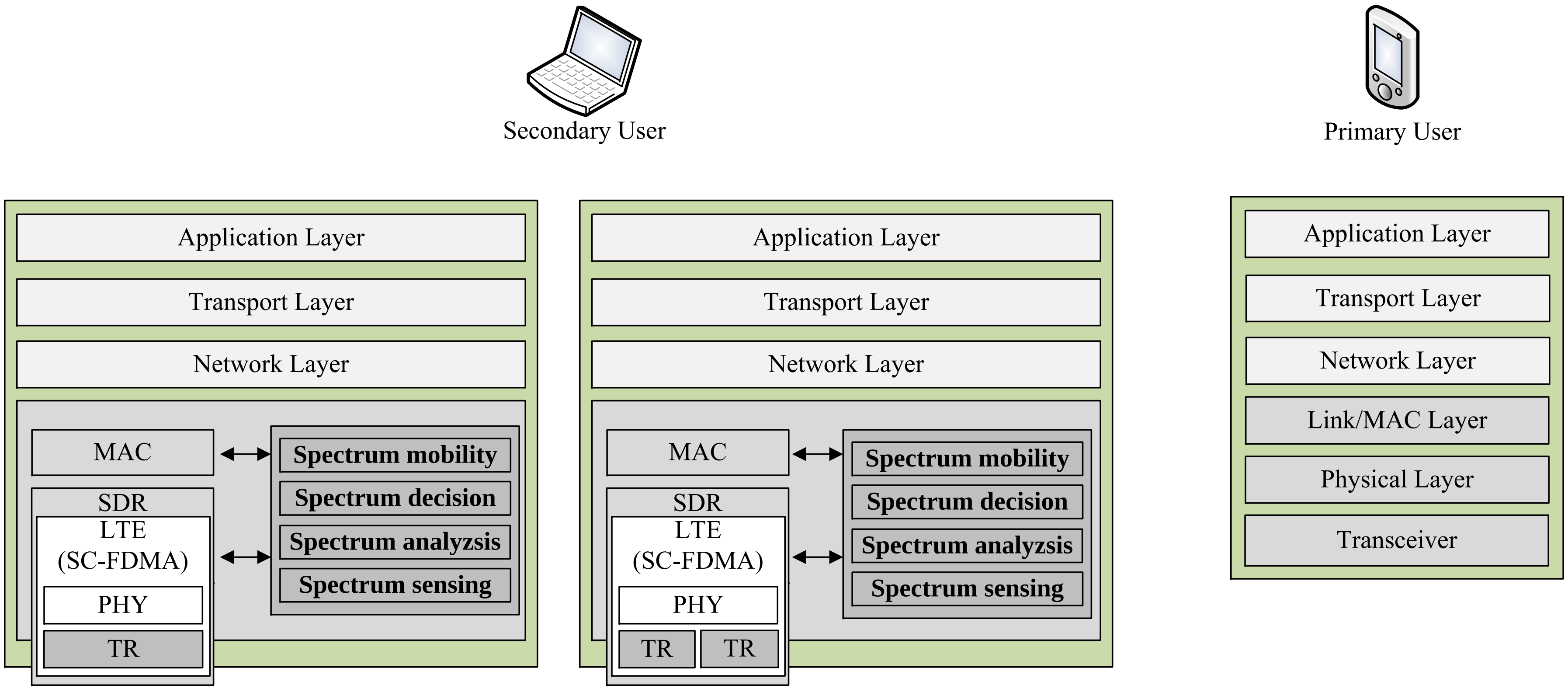
Cognition cycle

CR can **adapt to its operating environment** via **sensing in order to facilitate efficient communications**.



Gürkan Gür and Fatih Alagöz **"**Green Wireless Communications via Cognitive Dimension: An Overview," **IEEE Network** • March/April 2011.

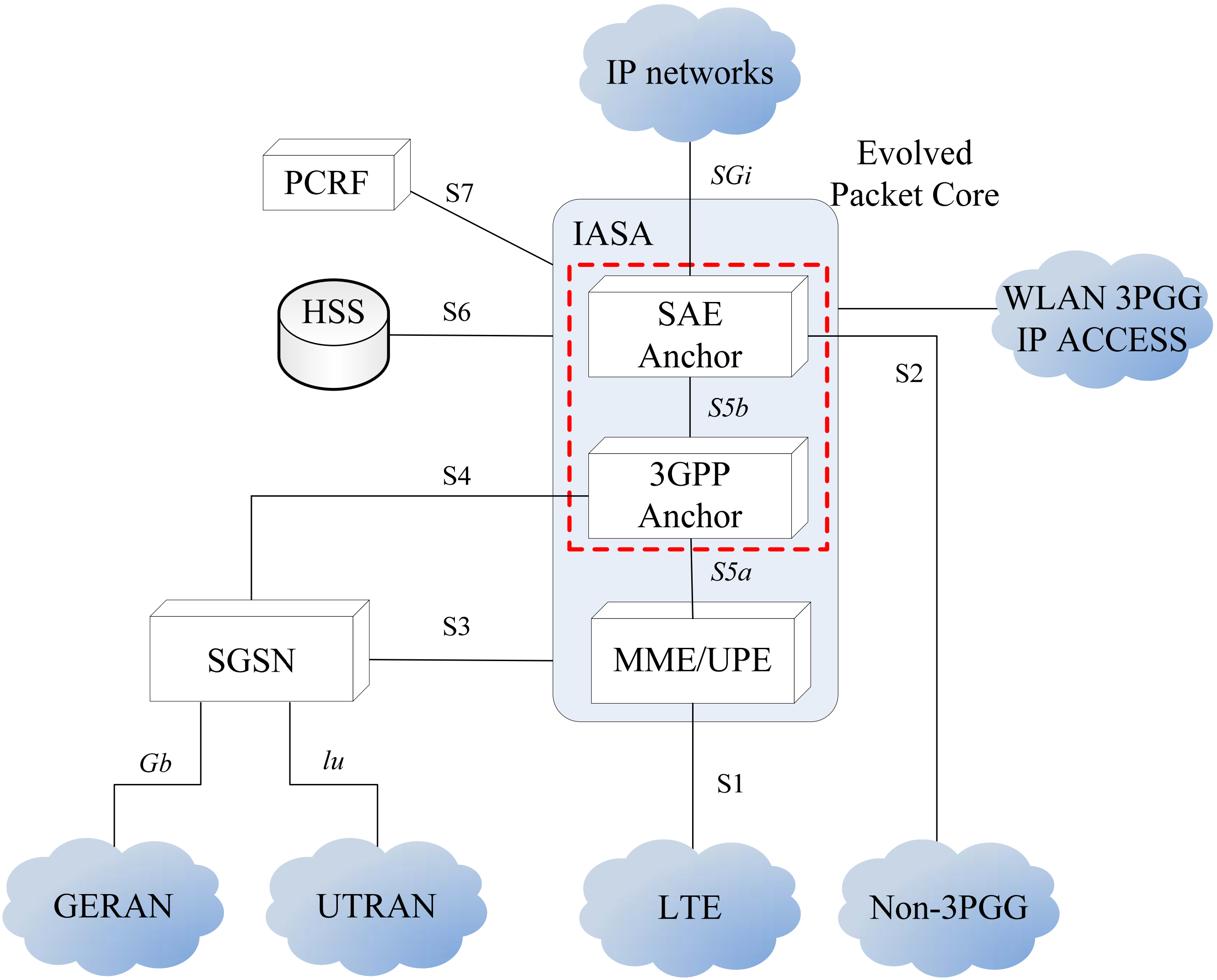
Cognitive user architecture



LTE

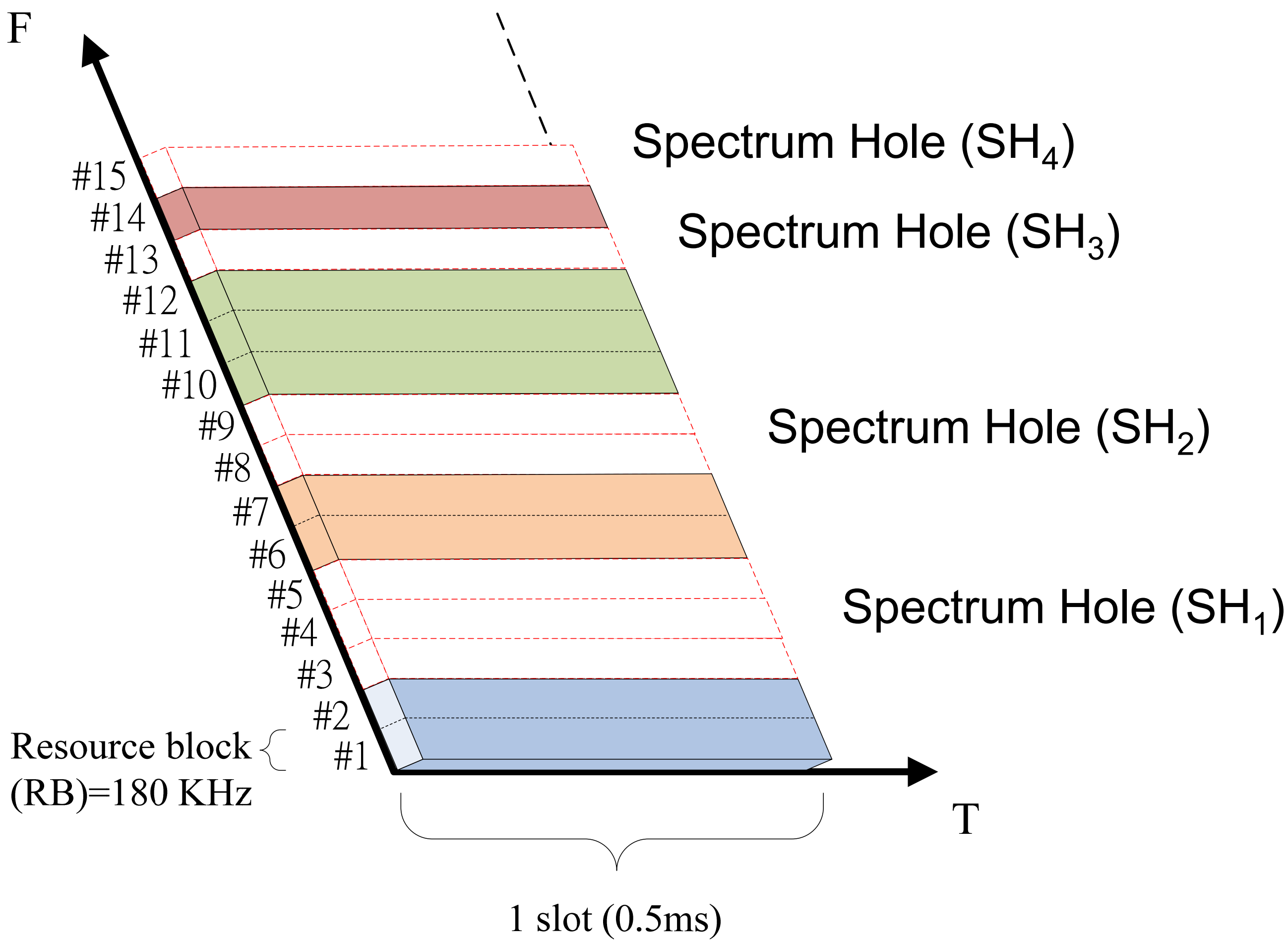
- **LTE** is developed based on the universal terrestrial radio access (UTRA) and high speed down-link packet access (HSDPA) and further strengthen its communications capacity to upload in order to enhance its quality of service. LTE have to coexist with 2G/3G systems, WLAN, WiMAX, etc.
  - With the development of wireless network technology, the wireless mobile access has been progressed by second-generation (2G) and third-generation (3G) cellular systems.
  - The Third Generation Partnership Project (3GPP) has proposed a 3G long term evolution (LTE) toward 4G cellular systems.

The 3GPP LTE system architecture



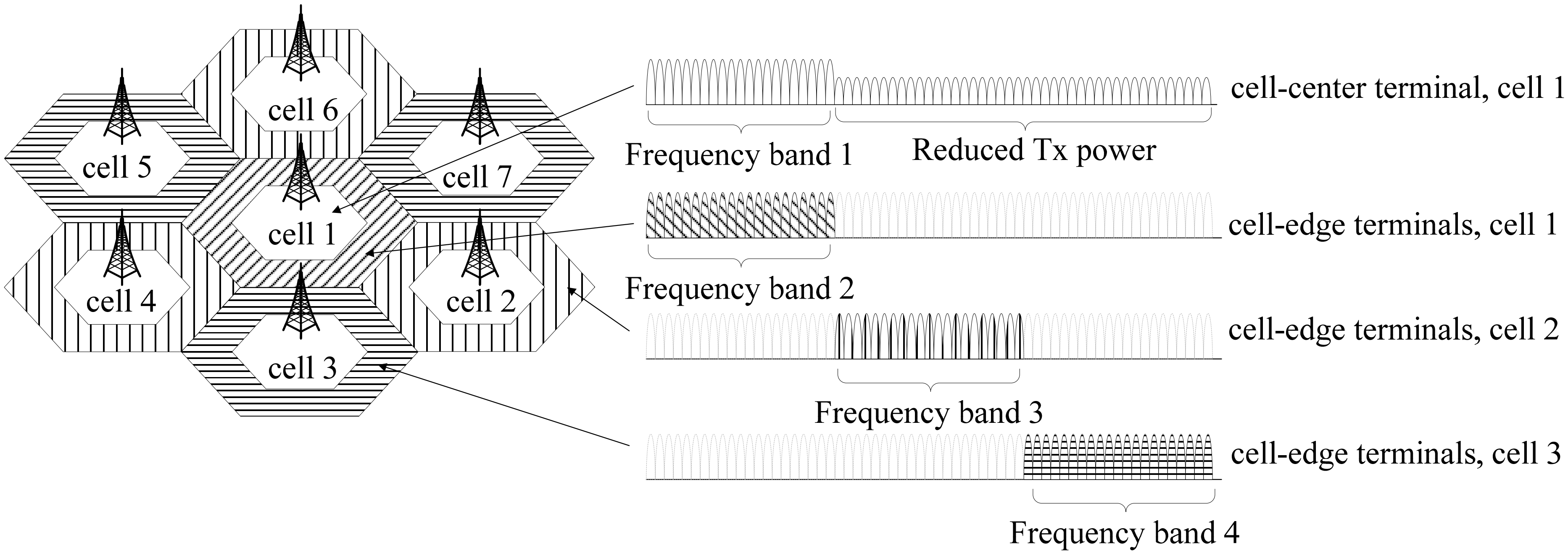
References: 3rd Generation Partnership Project TS36.300 , *"Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN) Overall description, Release 8, v8.8.0*

The spectrum architecture of LTE



(OFDM-based) Orthogonal frequency-division multiplexing

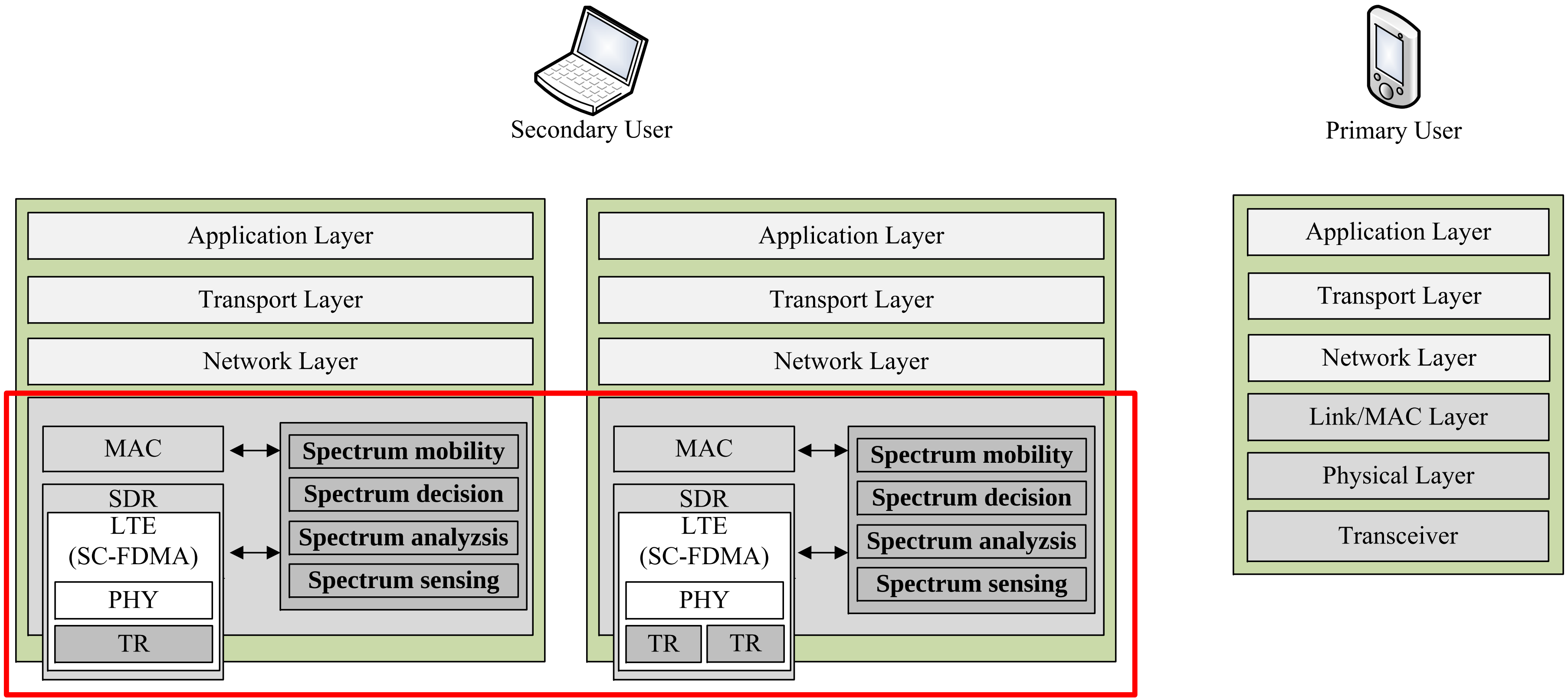
Inter-cell interference coordination



Software Defined Radio (SDR)

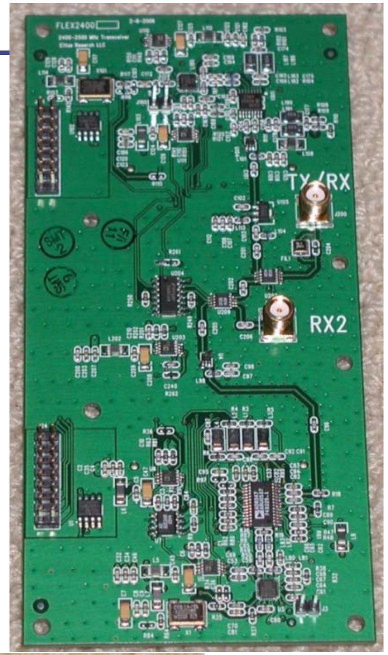
- **Software Defined Radio** (SDR) is a revolutionary technology to implement the CR networks.
  - The SDR is the first development to integrate different communication capabilities.
  - To upgrade the inconvenience and inflexibility of hardware architecture, a SDR with the programmable and reconfigurable modules is integrated with different communication protocols.
- A mobile terminal (SU) with SDR device uses the sensing device in the physical layer to periodically sense the **current signal strength** and the **idle spectrum resources**. With the sensed information, the SU dynamically selects a suitable spectrum hole for the spectrum mobility.

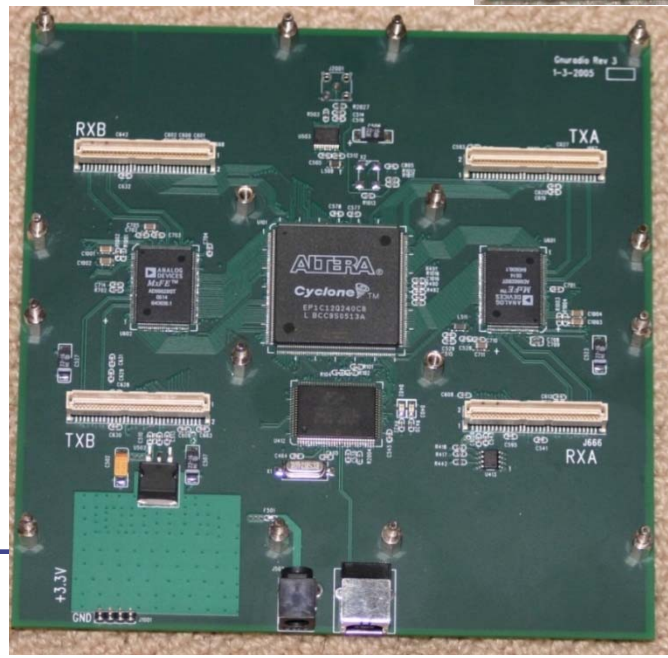
Cognitive user architecture



Software defined radio (SDR)

- SDR components
  - USRP+RFX2400
    - USRP (Universal Software Radio Peripheral)
  - GNU radio
    - GNU/Linux operating system
- SDR applications
  - Access different network by reconfigurable technique
  - Spectrum sensing
  - Spectrum analysis
  - Spectrum decision
  - Spectrum mobility

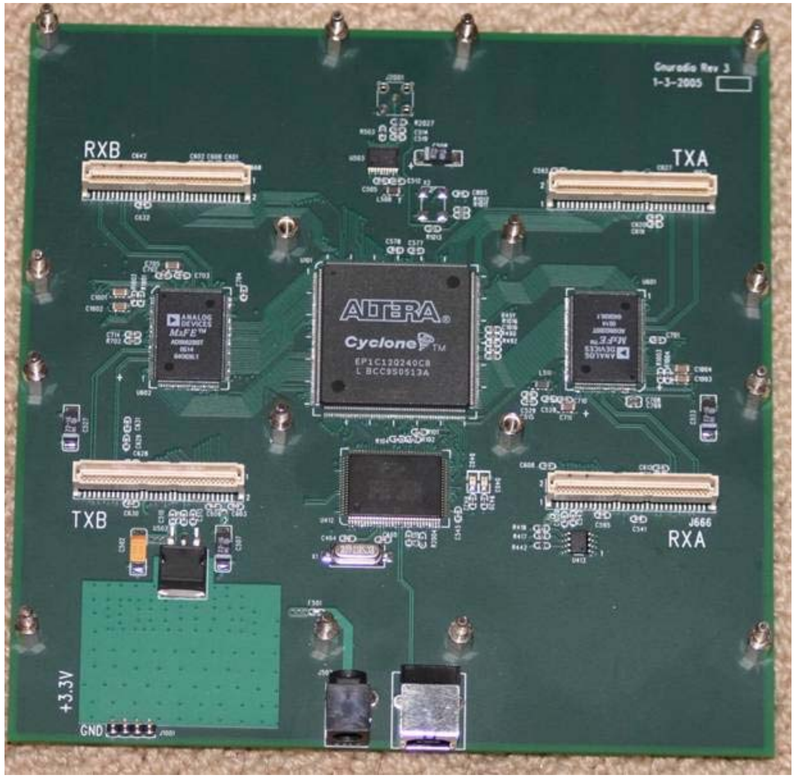




References: "USRP & RFX2400", *http://www.ettus.com*
"GNU radio", *http://gnuradio.org*

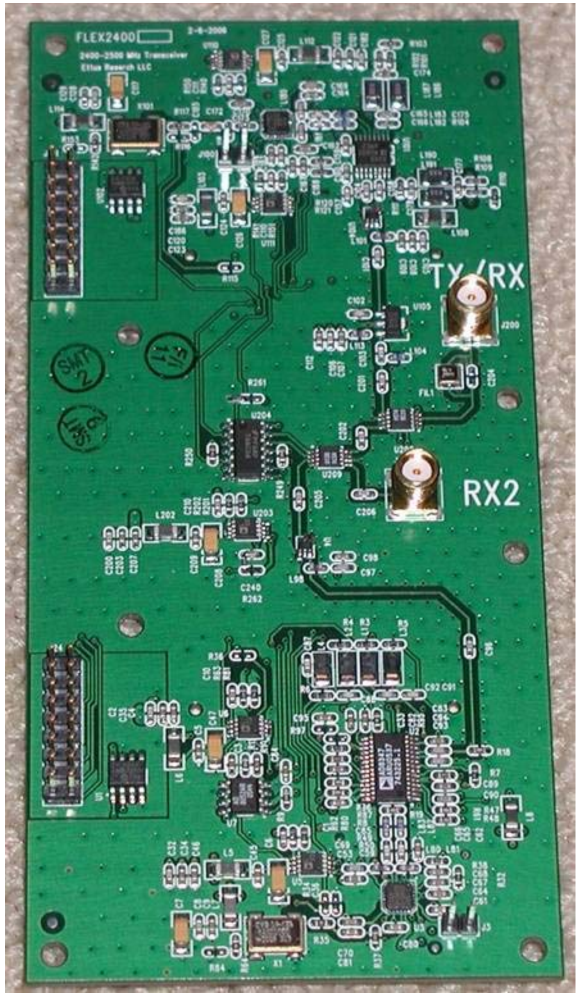
USRP Motherboard

- Four 64 MS/s 12-bit analog to digital Converters
- Four 128 MS/s 14-bit digital to analog Converters
- Four digital downconverters with programmable decimation rates
- Two digital upconverters with programmable interpolation rates
- High-speed USB 2.0 interface (480 Mb/s)
- Capable of processing signals up to 16 MHz wide
- Modular architecture supports wide variety of RF daughterboards

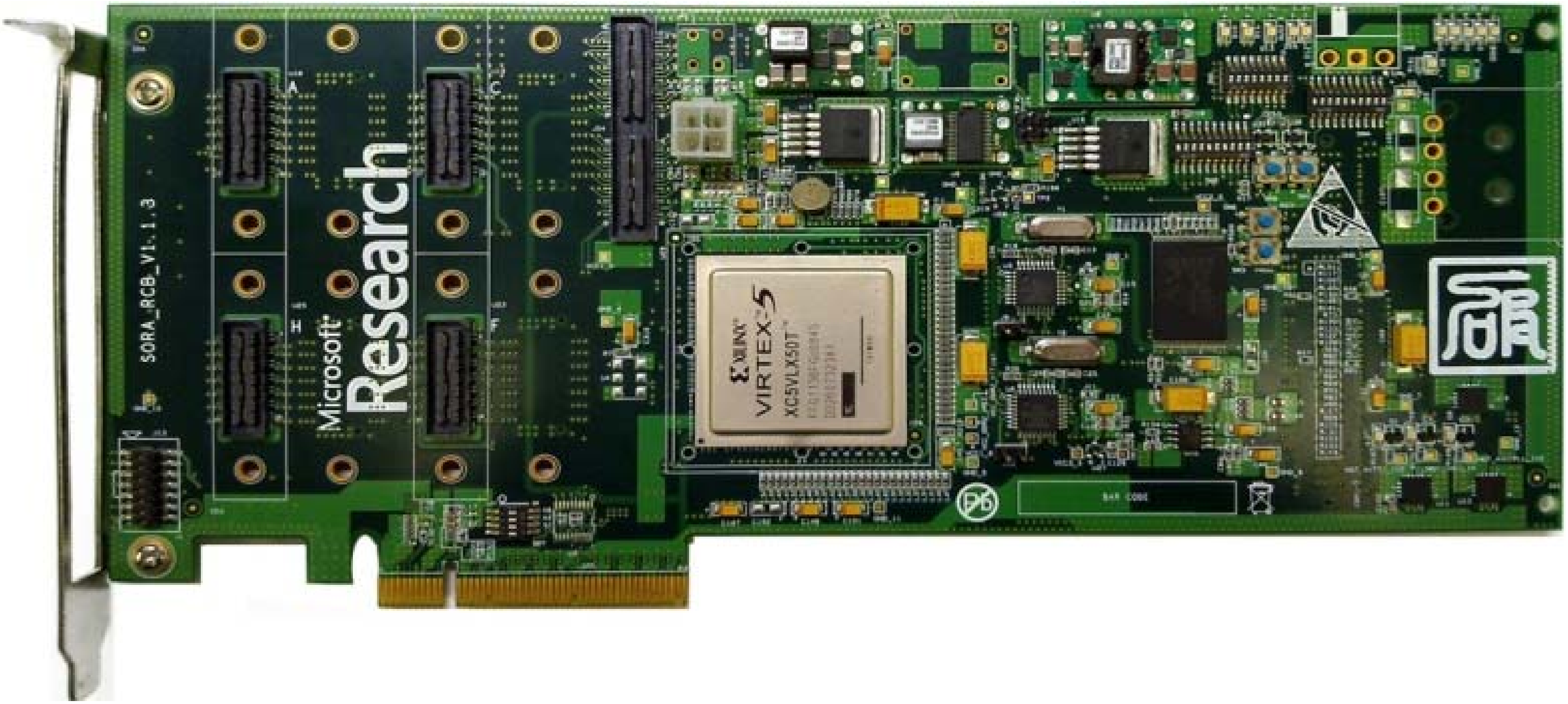


RFX2400 2.3-2.9 GHz Transceiver

- 50mW output (17dBm)
- with a bandpass filter around the ISM band (2400-2483 MHz).
- The filter can be easily bypassed, allowing for coverage of the full frequency range.



SORA



USRP

RF1
RF2
RF3
RF4
CLK I/O
Ettus
Research
5VDC
USB
USRP
Universal Software Radio Peripheral
www.ettus.com

USRP2

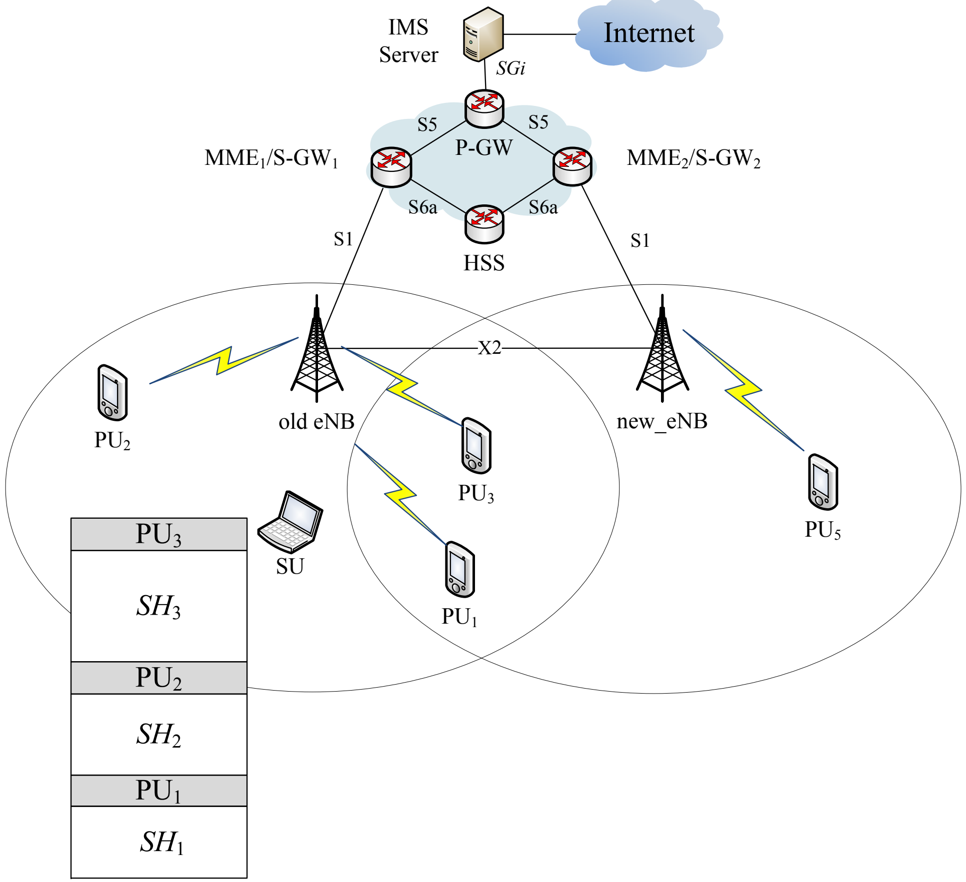

Ettus Research
USRP2
RF1
RF2
REF CLOCK
PPS IN
SD MEMORY
MIMO EXPANSION
GB ETHERNET
A B
C D
E F
POWER 6V DC 3A

USRP、USRP2、SORA 比較表格

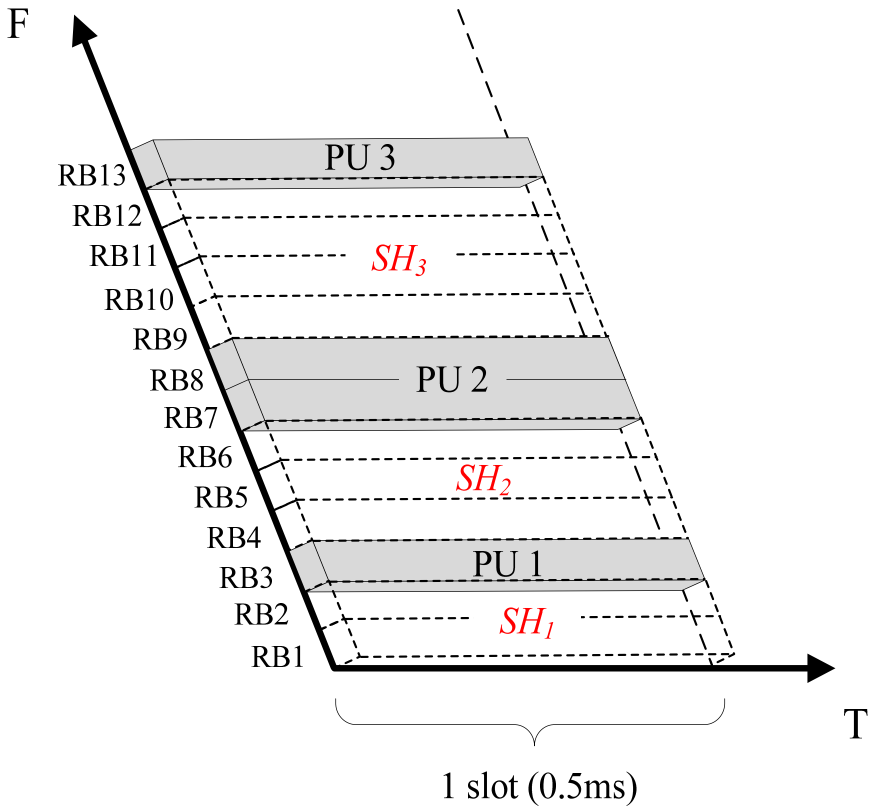
	USRP1	USRP2	SORA
價錢	32000(僅母板)	64000(僅母板)	與USRP2價格相當
程式環境	Python　C/C++	同USRP1，但需部份修改	C/C++
連接方式	USB2.0	Gigabit Ethernet Interface	PCIe (筆電無法連接)
傳輸速度	400Mbps	2 Gbps	64Gbps (PCIe x 32)
開發工具	gnuradio-3.3	gnuradio-3.3	微軟釋出 SDK1.02
網路資源	多	較USRP1少	極少
子板	DBSRX : 800MHz ~ 2.4GHz 固定頻段子板有以下頻段: 50M~1G,750M~1050M,1150M~1450M,1.5G~2.1G,2.3G~2.9G,2.45G~5.9G	同USRP1	僅是平台，需配合其它子板(WARP USRP)
其它		1.USRP2儲存在SD卡 2.信號帶寬高達100 MHz	1. 已實現 IEEE802.11a/b/g的PHY，MAC layer protocol 2. 已實現 3GPP LTE的上行 3. 高帶寬可支持20MHz 4. 可自由分配多個CPU對SORA的平行處理

Our Implementation

Spectrum sensing and spectrum distribution



(a)



(b)

Contribution

- To our knowledge, this work is the first study to consider the handover problem over CR networks.
  - The main contribution of this paper is to present a cross-layer protocol of spectrum mobility (layer-2) and handover (layer-3) in cognitive LTE networks.
  - This result "**A Cross-Layer Protocol of Spectrum Mobility and Handover in Cognitive LTE Networks**," is accepted by Simulation Modelling Practice and Theory, (SCIE, EI)

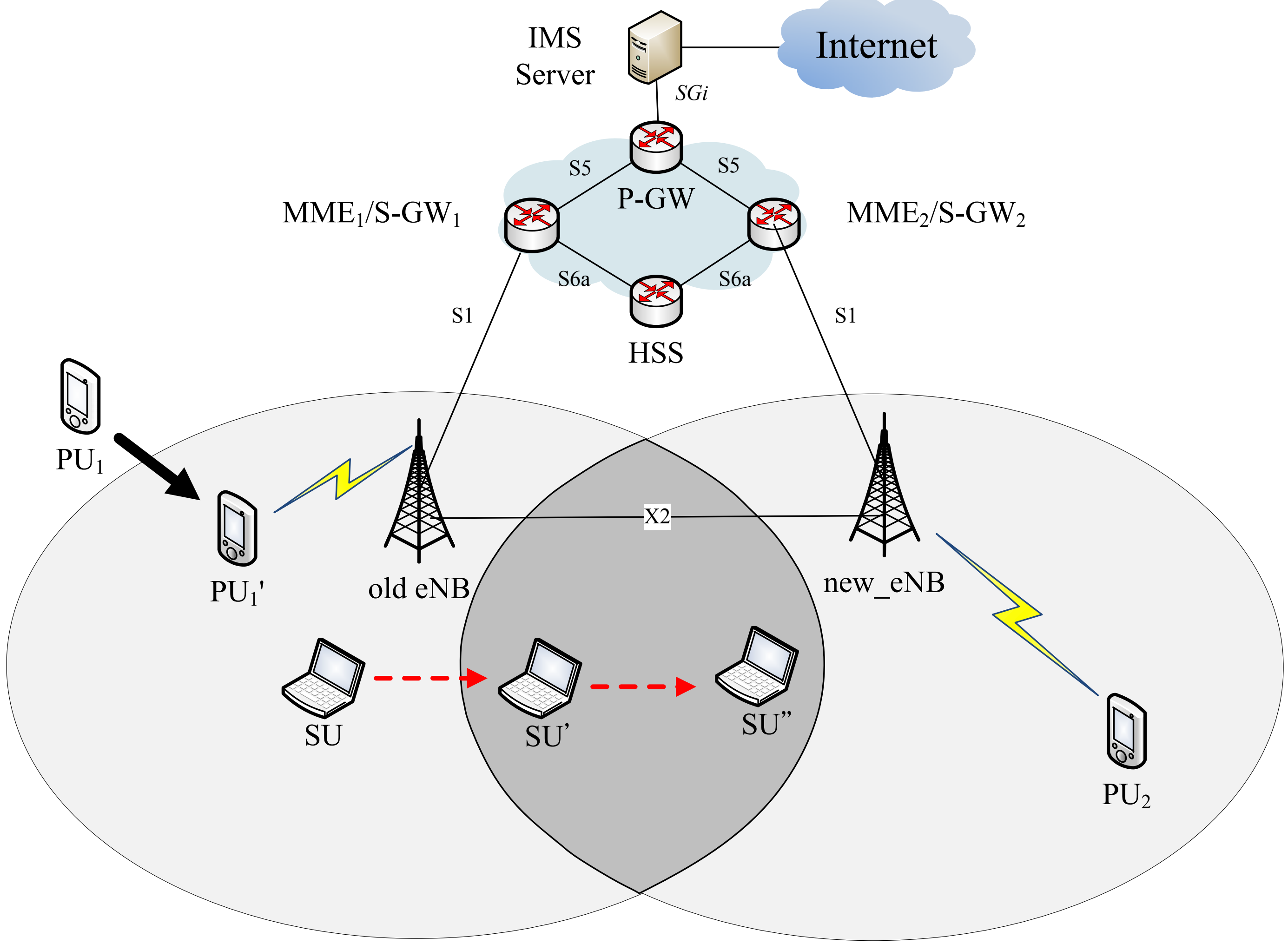
3. Related works

- There are some literatures for layer 2 channel selection in cognitive radio.
  - Jo *et al.*, ”Efficient Spectrum Matching Based on Spectrum Characteristics in Cognitive” *IEEE Wireless Telecommunications Symposium* (**WTS 2008**)
    - The prediction is based on **service required time**.
  - Hoyhtya *et al.*, ”Performance Improvement with Predictive Channel Selection for Cognitive Radios” *IEEE Cognitive Radio and Advanced Spectrum Management* (**CogART 2008**)
    - The prediction is based on **spectrum hole idle time**.

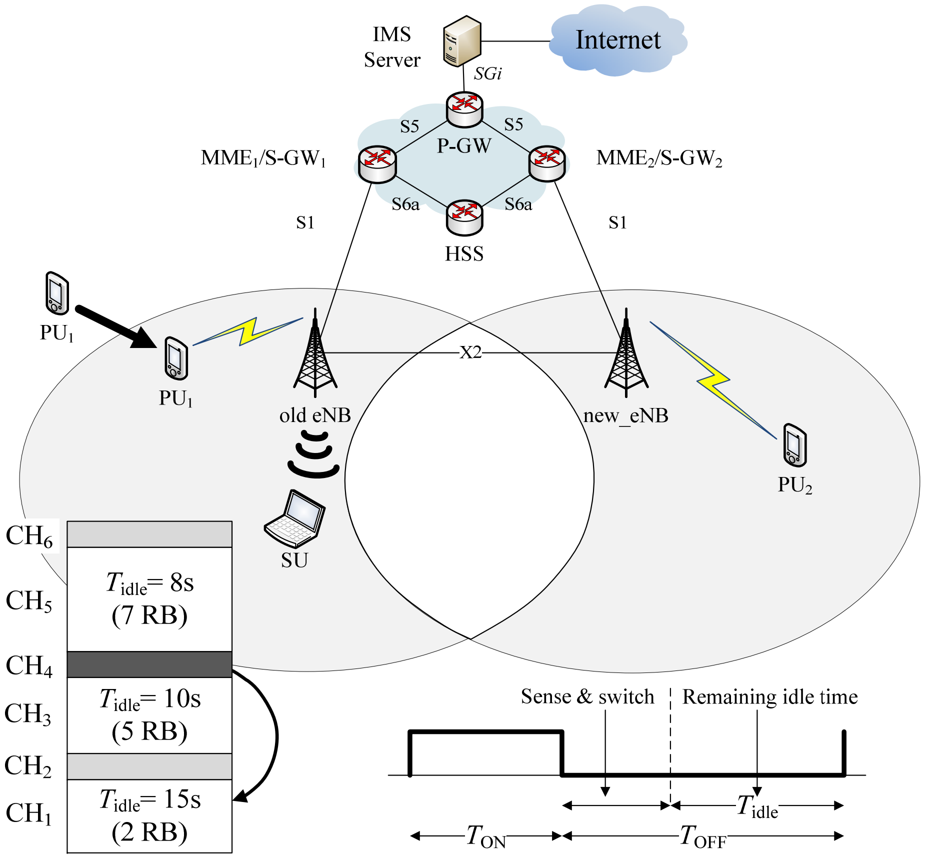
4. Motivation and basic idea

- In layer 3 handover issue, the layer 2 information is not considered in handover procedure.
- In the flexible bandwidth condition, the **maximum idle time spectrum hole** selection scheme with **narrow bands** may decrease the successful transmission rate.
  - The prediction of the idle time does not consider the channel and user characters.
- The proposed scheme uses the **expected transmission time** as our new prediction strategy.

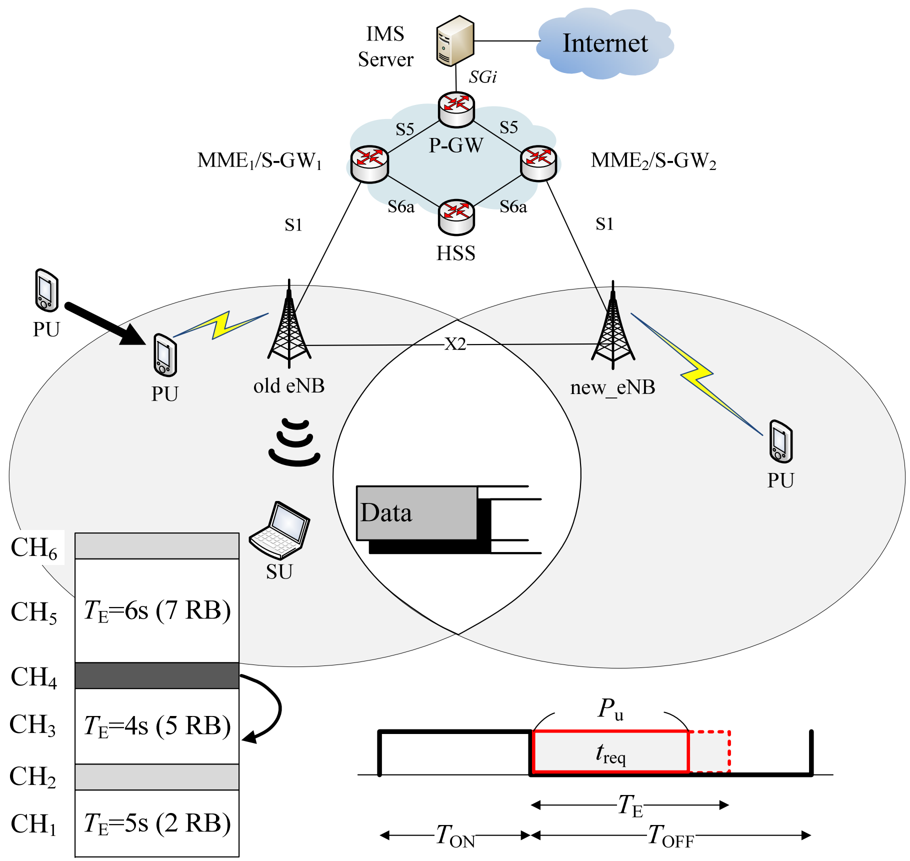
System model



Protocol Comparison



(a) The prediction is based on **maximum spectrum idle time**



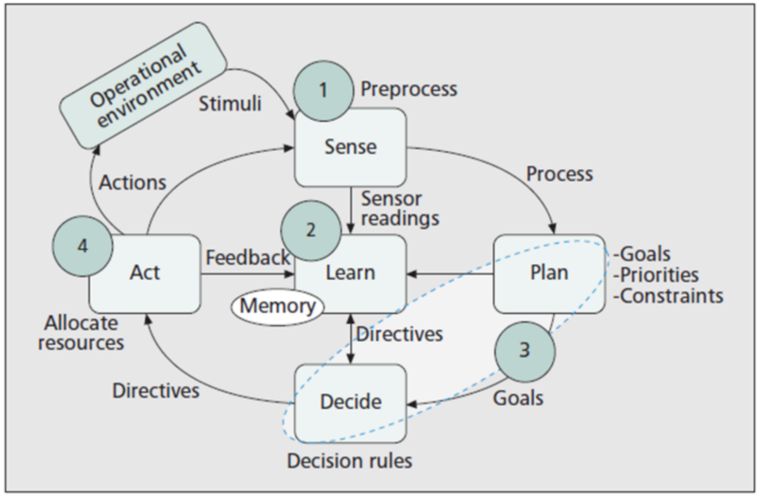
(b) The prediction is based on **minimum expected transmission time**

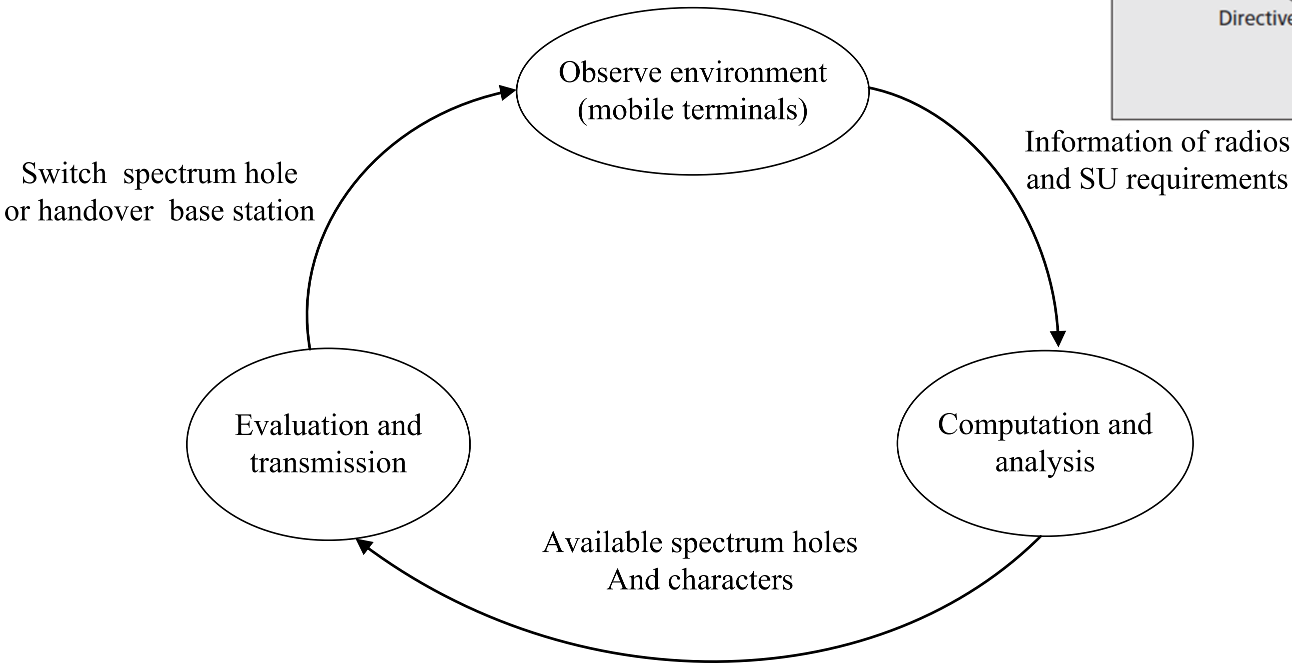
Basic Idea

- We adopt the minimum expected transmission time to predict the spectrum holes usage and availability.

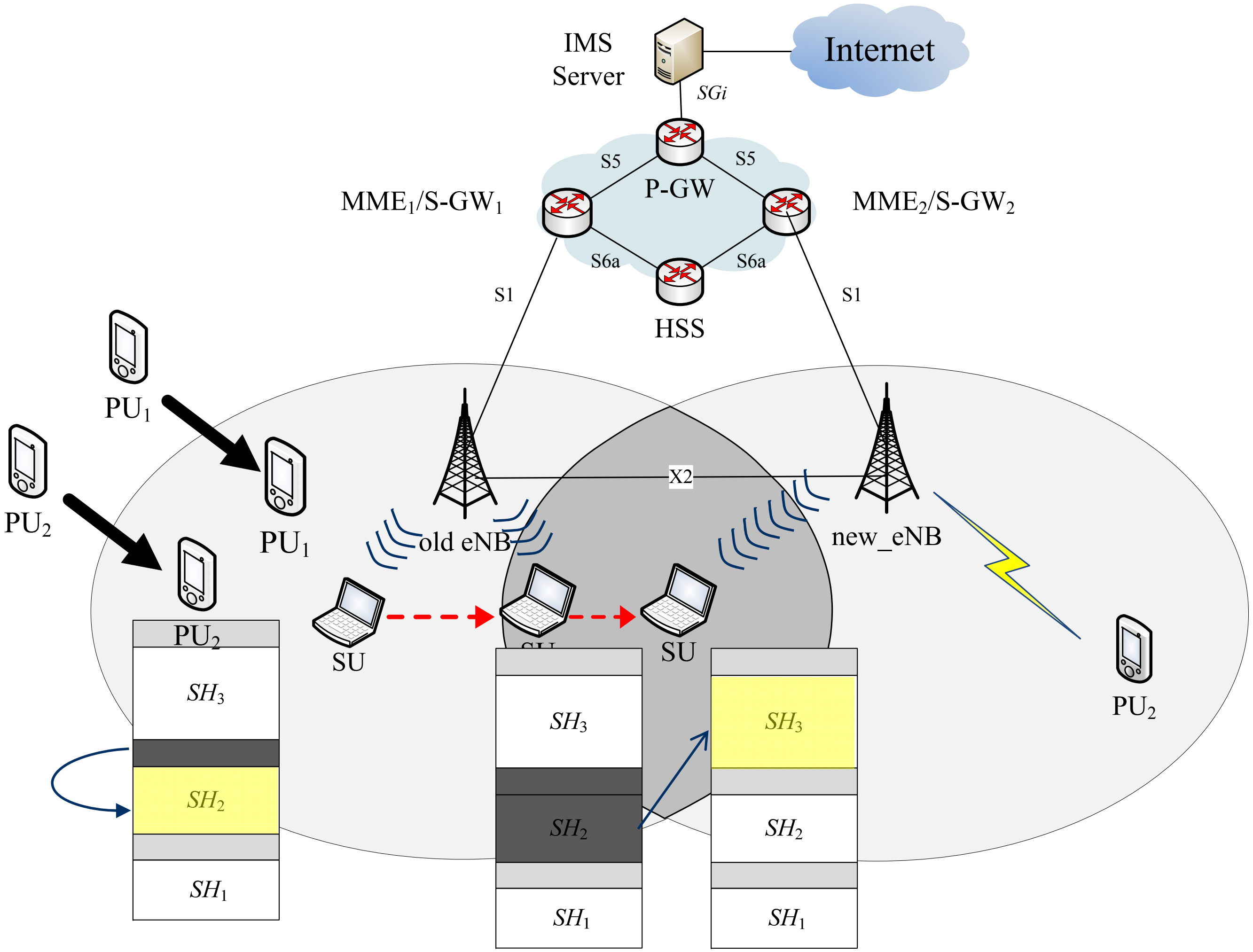
5. Hybrid spectrum mobility and handover protocol in 3GPP cognitive LTE systems

- Three phases
  - **Environment observation phase**
  - **Computation and analysis phase**
  - **Evaluation and transmission phase**



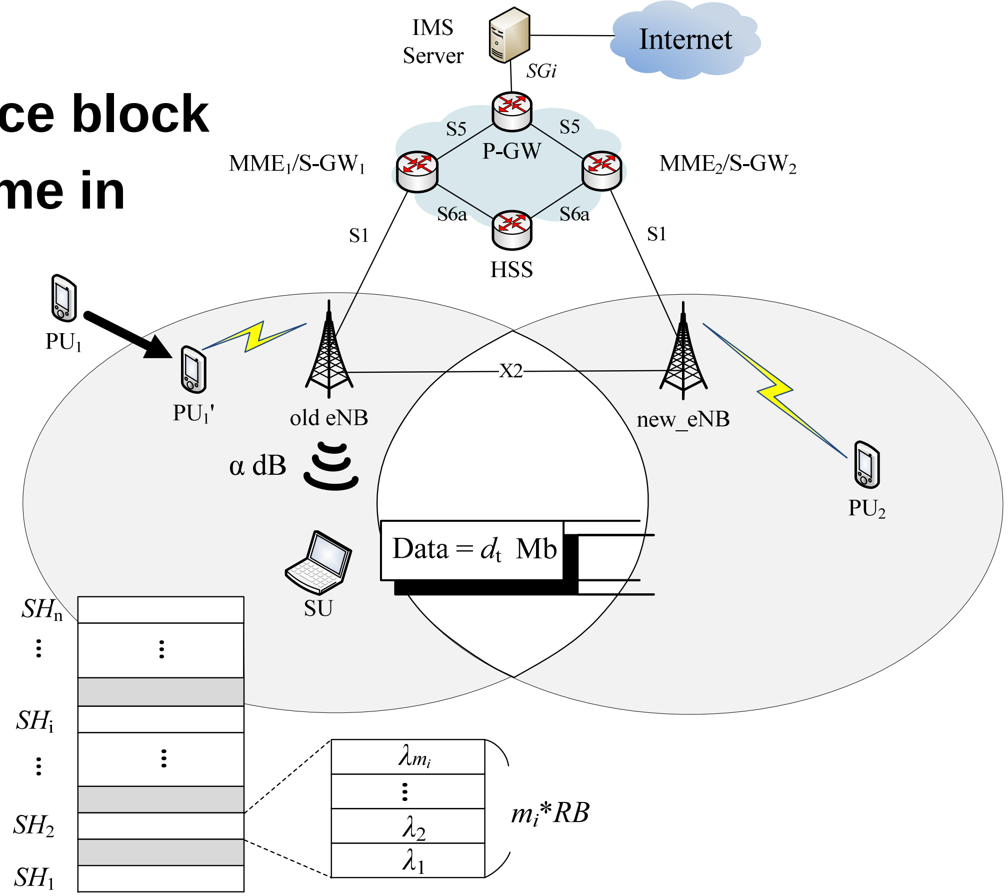


Protocol Overview

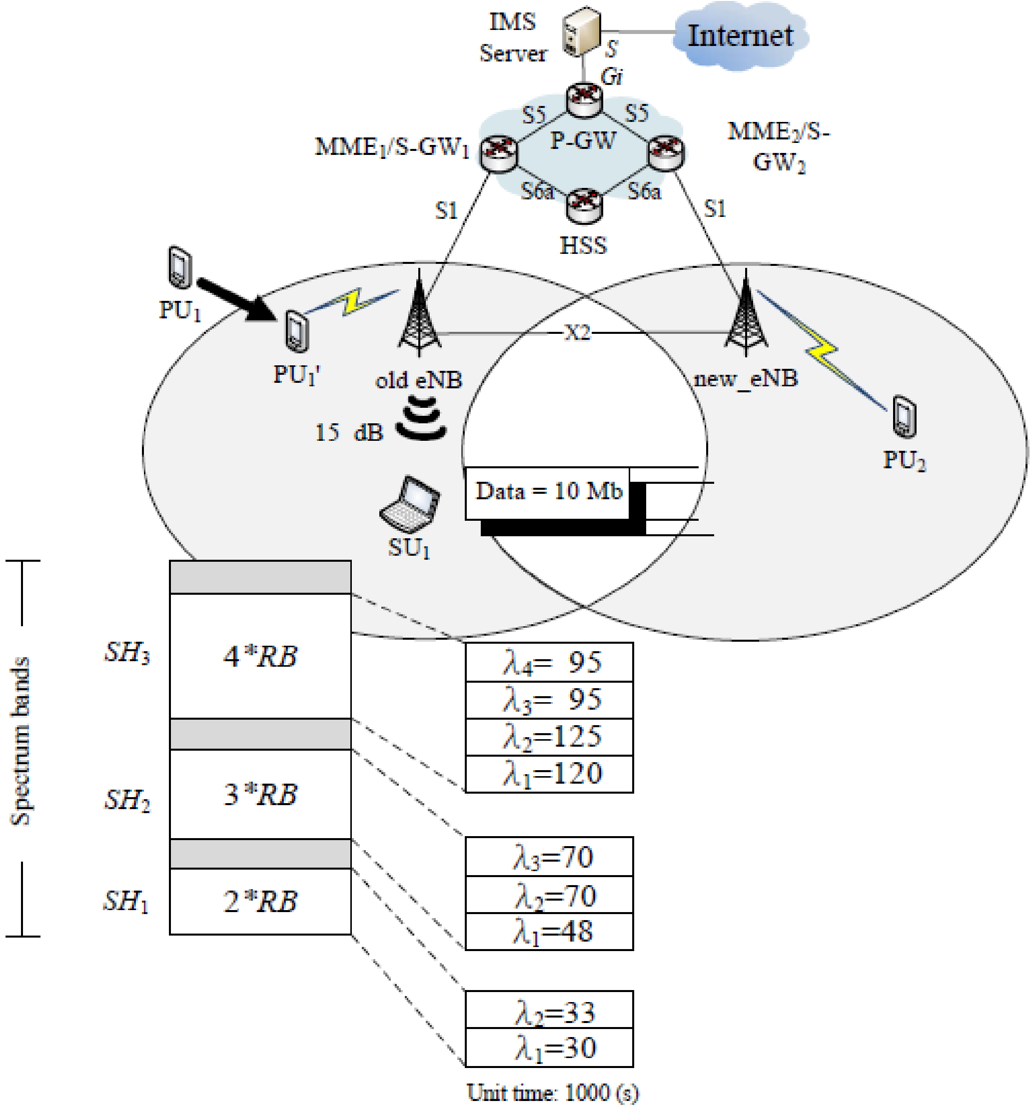


1. Environment observation phase

- Observed information
  - α: received signal strength (dB)
  - d_t: current service data size
  - λm_i: **the number of resource block be occupied in unit time in spectrum hole *i*.**

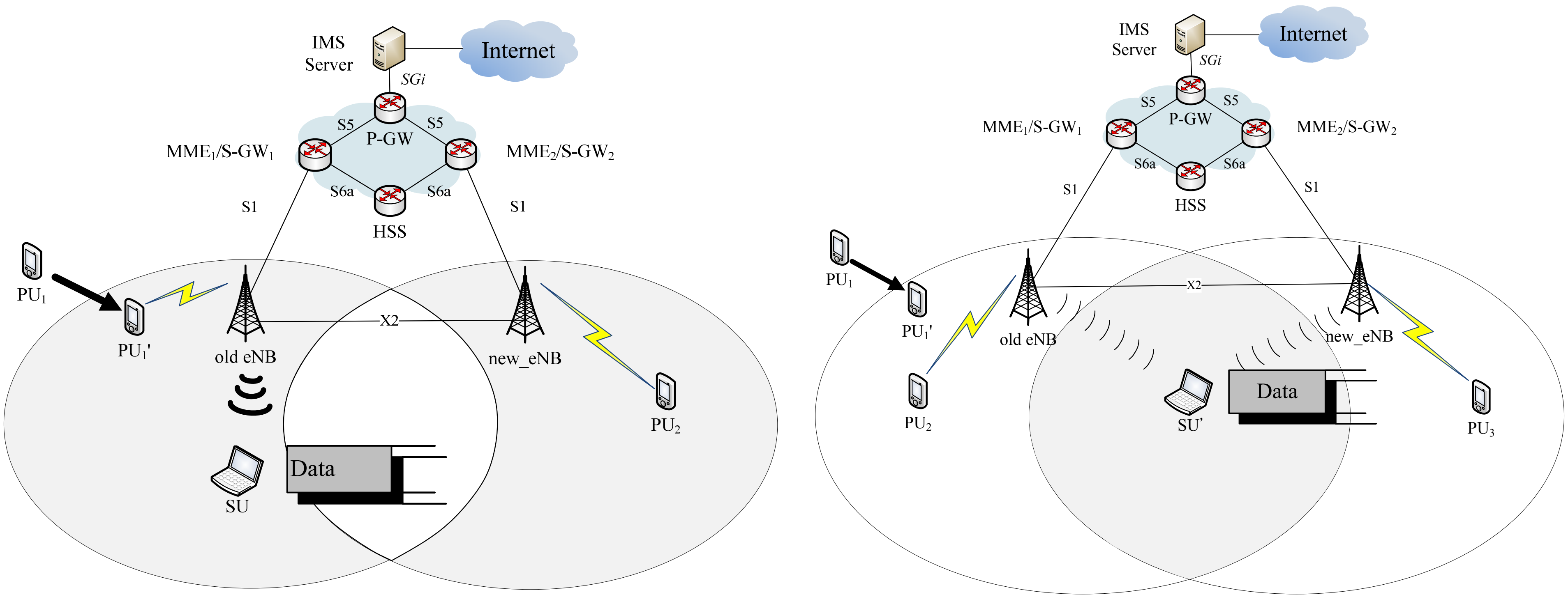


Observed results



2. Computation and analysis phase

- Divided into two case
  - SU is in the non-overlapped area
  - SU is in the overlapped area



Computation and analysis (cont.)

- In this phase, the **transmission rate**, the **required time of data transmission**, and the **probability of spectrum hole unoccupied** are analyzed.
- Some communication formulas,
  - Signal strength to SNR

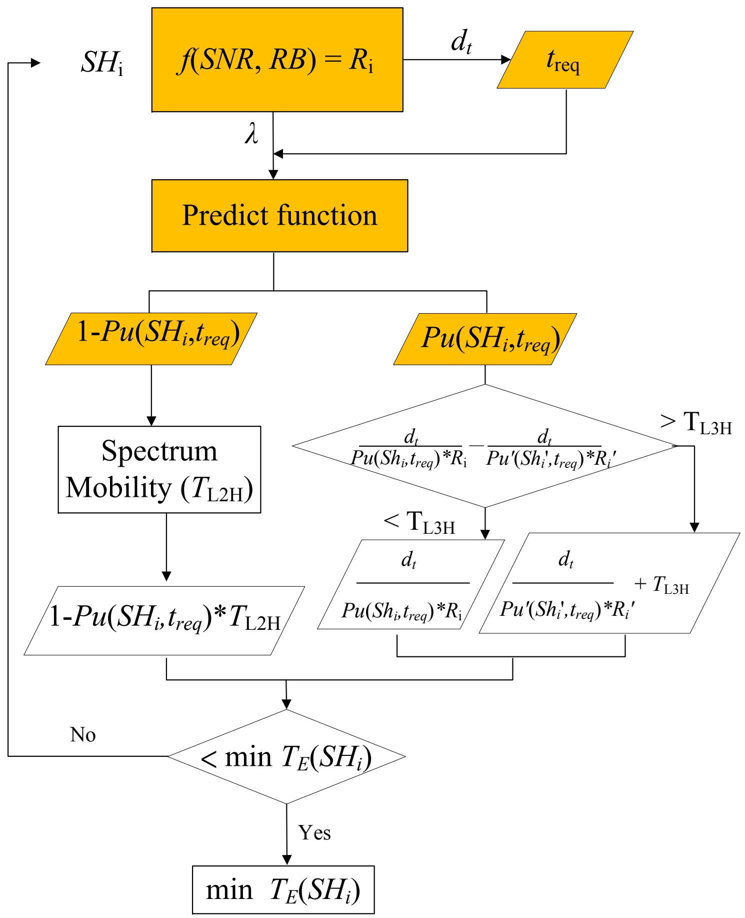
$$dB = 10 \log SNR$$

  - Shannon theorem

$$C = B \times \log_2(1 + SNR)$$

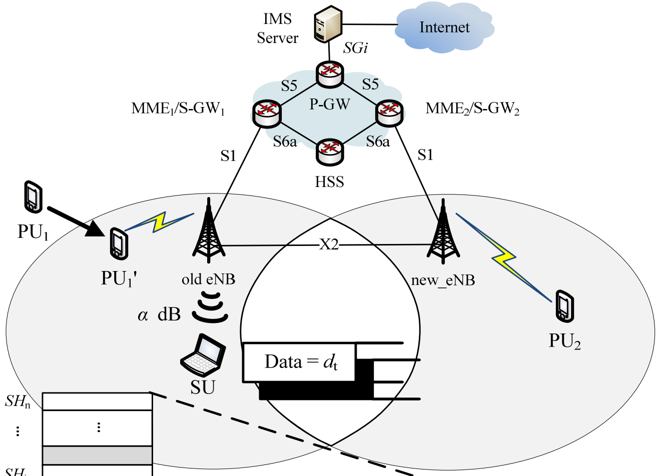
  - Poisson distribution

$$P(k,T) = \frac{(\lambda T)^k}{k!} e^{-\lambda T}$$



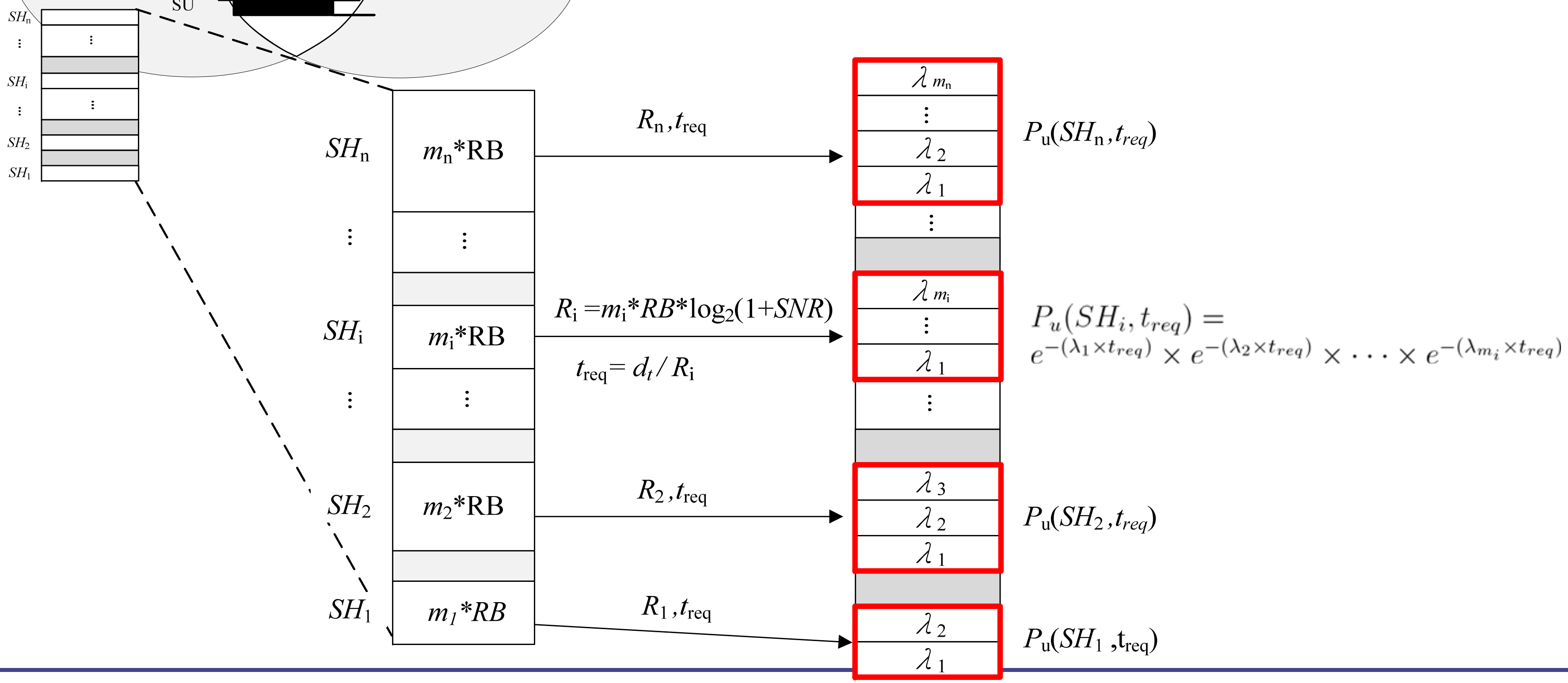
Reference: CE Shannon. "A mathematical theory of communication". *ACM SIGMOBILE Mobile Computing and Communications Review*, 5(1):3–55, 2001.
L. Bortkiewicz " Das Gesetz der kleinen Zahlen".. *BG Teubner, Leipzig, 1898.*

SU in non-overlapped area

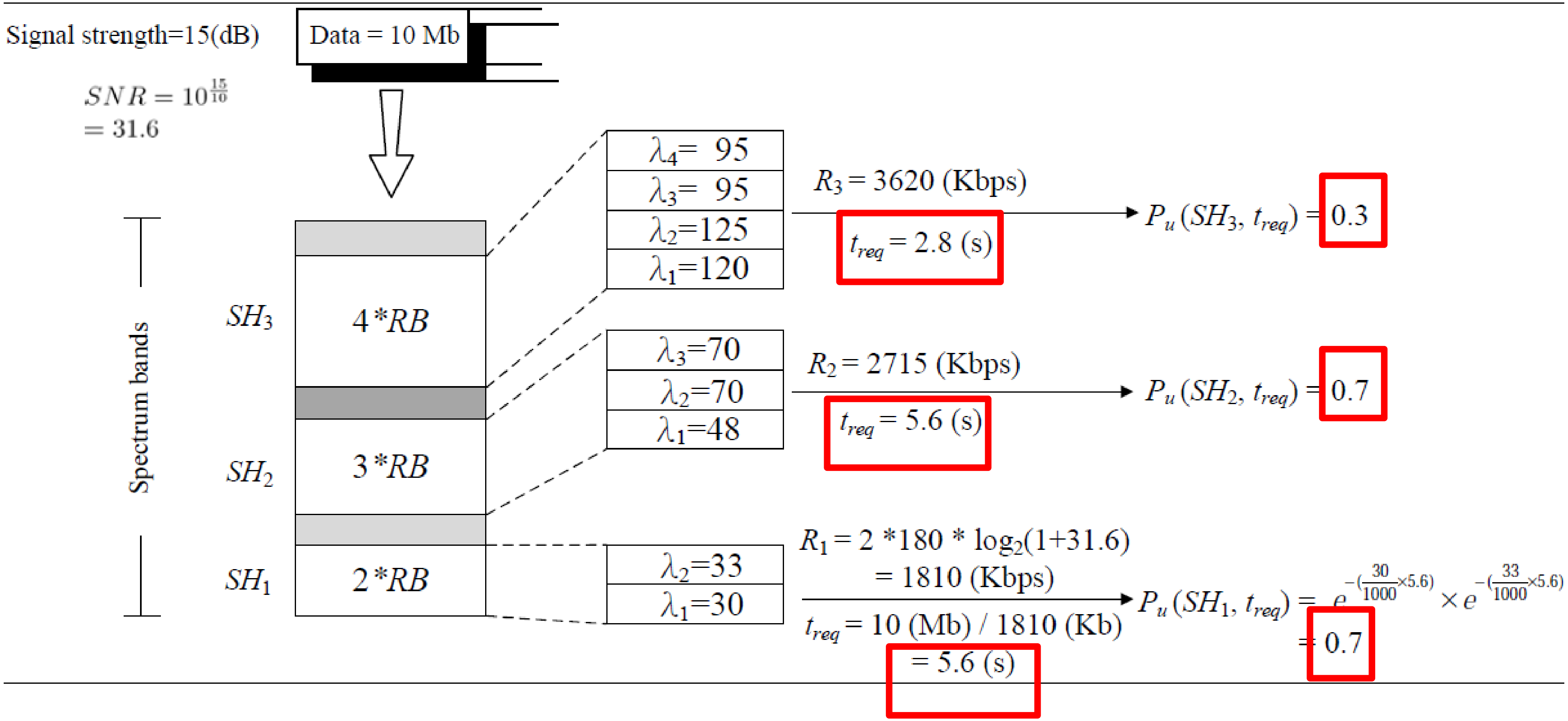


$$P_u(SH_i, t_{req}) = \prod_{n=1}^{m_i} P_n(0, t_{req}) = \prod_{n=1}^{m_i} (e^{-\lambda_n t_{req}})$$

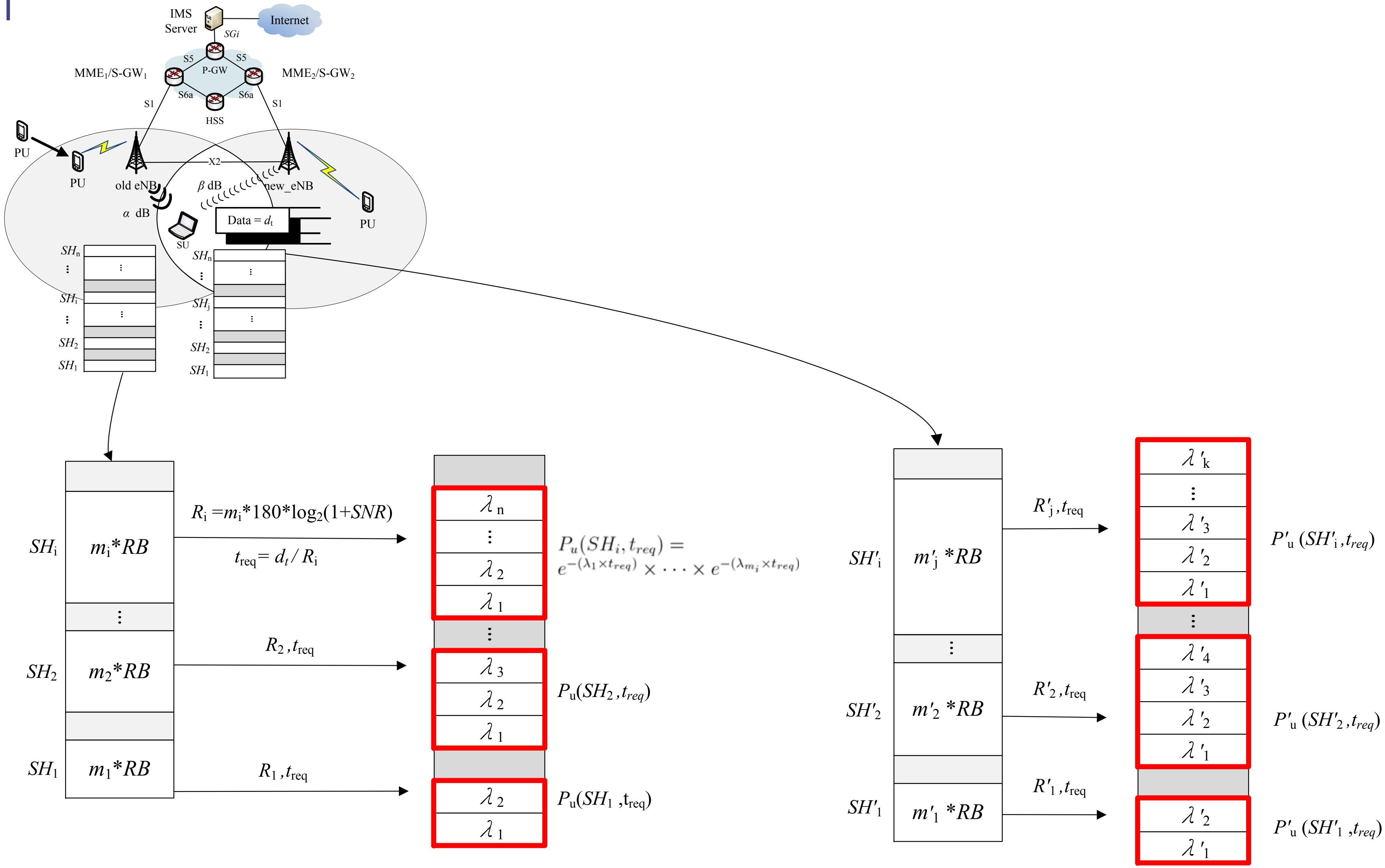
: Probability of spectrum hole SH_i unoccupied by PU within time period of t_{req}.



SU is in the non-overlapped area



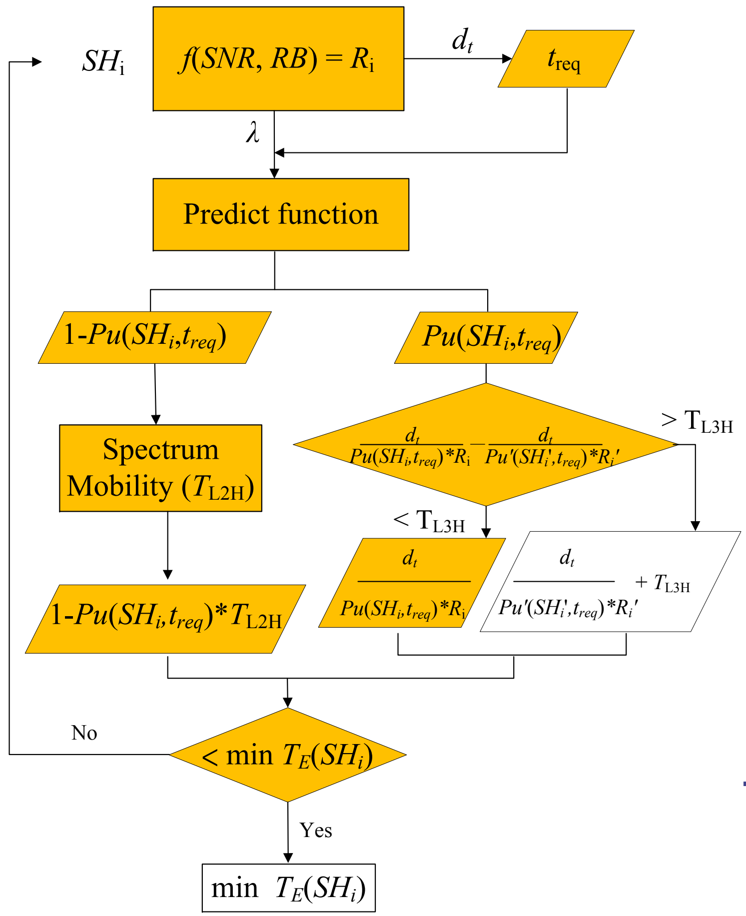
SU is in overlapped area



3. Evaluation and transmission phase (non-overlapped area)

- The expected transmission time of SU service data T_E

$$T_E = \frac{d_t}{P_u(SH_i, t_{req}) \times R_i} + (1 - P_u(SH_i, t_{req})) \times T_{L2H}$$

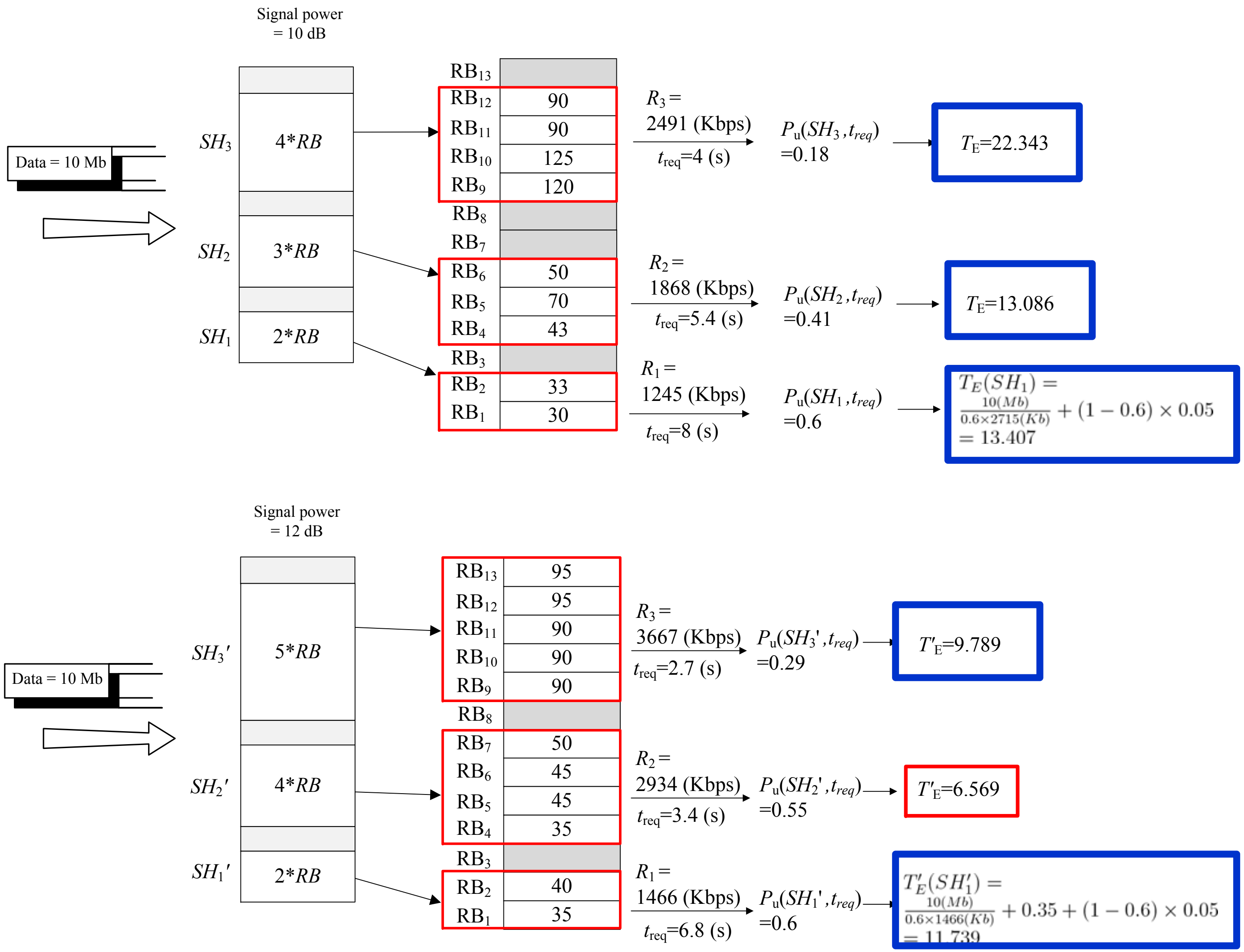


Evaluation and transmission phase (overlapped area)

- MN is performed the spectrum mobility if

$$\frac{d_t}{P_u(m_i,t_{req})\times R_i} + (1 - P_u(m_i, t_{req})) \times T_{L2H}$$
$$-\frac{d_t}{P'_u(m'_i,t'_{req})\times R'_i} - (1 - P'_u(m'_i, t'_{req})) \times T_{L2H} > T_{L3H}$$

Example



Signal power
= 10 dB
Data = 10 Mb
SH3
4*RB
SH2
3*RB
SH1
2*RB
RB13
RB12 90
RB11 90
RB10 125
RB9 120
RB8
RB7
RB6 50
RB5 70
RB4 43
RB3
RB2 33
RB1 30
R3 = 2491 (Kbps)
treq=4 (s)
Pu(SH3,treq) =0.18
TE=22.343
R2 = 1868 (Kbps)
treq=5.4 (s)
Pu(SH2,treq) =0.41
TE=13.086
R1 = 1245 (Kbps)
treq=8 (s)
Pu(SH1,treq) =0.6
TE(SH1) = 10(Mb) / 0.6×2715(Kb) + (1 − 0.6) × 0.05 = 13.407
Signal power
= 12 dB
Data = 10 Mb
SH3'
5*RB
SH2'
4*RB
SH1'
2*RB
RB13 95
RB12 95
RB11 90
RB10 90
RB9 90
RB8
RB7 50
RB6 45
RB5 45
RB4 35
RB3
RB2 40
RB1 35
R3 = 3667 (Kbps)
treq=2.7 (s)
Pu(SH3',treq) =0.29
T'E=9.789
R2 = 2934 (Kbps)
treq=3.4 (s)
Pu(SH2',treq) =0.55
T'E=6.569
R1 = 1466 (Kbps)
treq=6.8 (s)
Pu(SH1',treq) =0.6
T'E(SH'1) = 10(Mb) / 0.6×1466(Kb) + 0.35 + (1 − 0.6) × 0.05 = 11.739

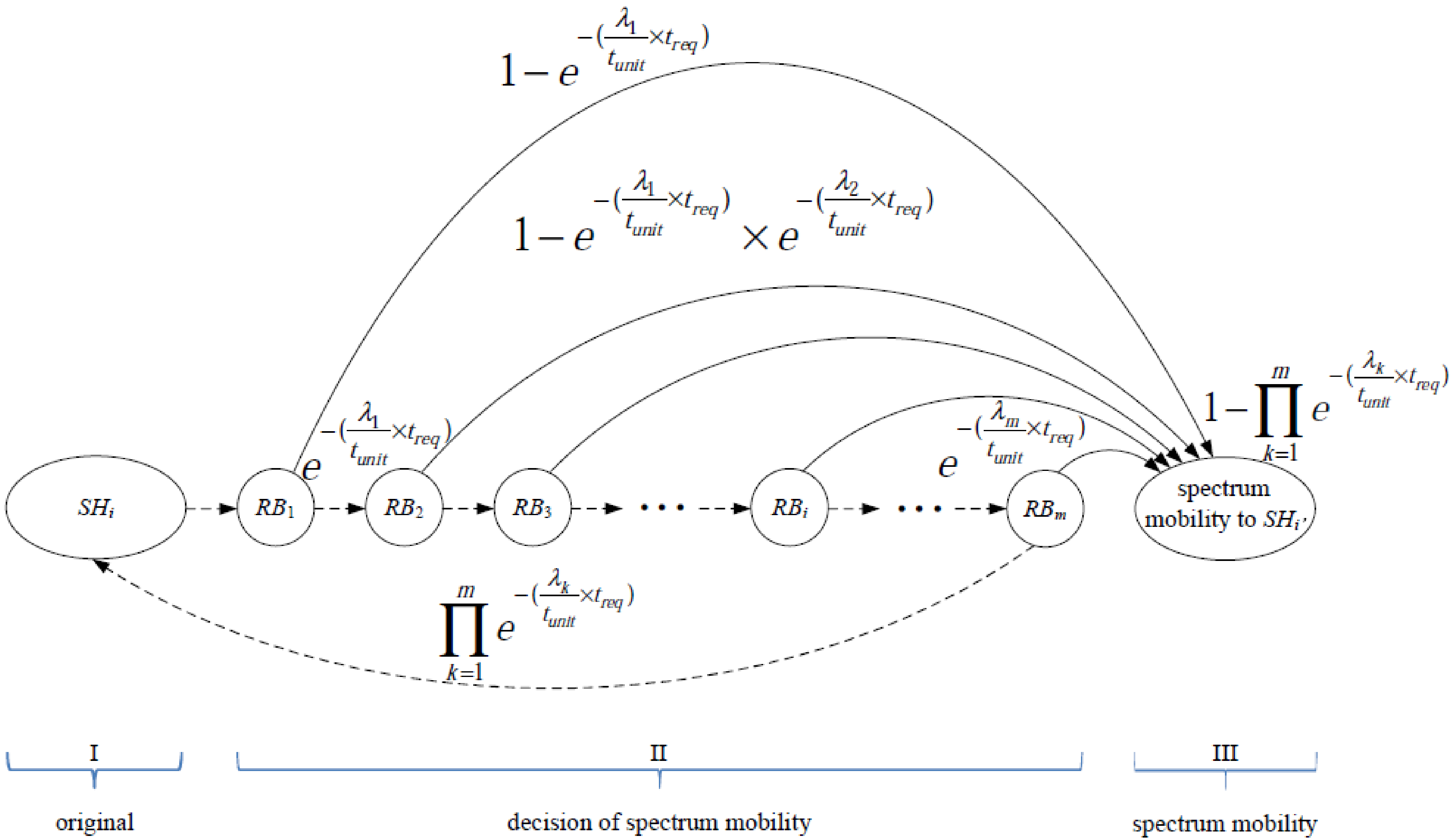
Performance analysis

- An analytic model is developed to analyze the **total transmission time** and the **throughput** for our proposed scheme.
- The Markov chain model is adopted.
- The Markov chain is represented as a directed graph

The state transition information is given below.

- SH_i to RB_1: indicates that the previous packet was completely transmitted completely and the next packet starts to be transmitted.
- RB_i to RB_{i+1}: RB_i has the probability of $e^{-(\frac{\lambda_i}{t_{unit}} \times t_{req})}$ if RB_i is not reclaimed by a PU.
- RB_i to "spectrum mobility to $SH_{i'}$": RB_i has the probability of $1 - \prod_{k=1}^{i} e^{-(\frac{\lambda_k}{t_{unit}} \times t_{req})}$ if the RB_i is reclaimed by a PU and RB_1 to RB_{i-1} are not reclaimed by the PU.
- RB_m to SH_i: RB_m has the probability of $\prod_{k=1}^{m} e^{-(\frac{\lambda_k}{t_{unit}} \times t_{req})}$ if RB_m is not reclaimed by a PU. This implies that all m RB_i are not reclaimed by a PU and the SU_x can continually uses the SH_i.

Relation between resource blocks in the scenario one.



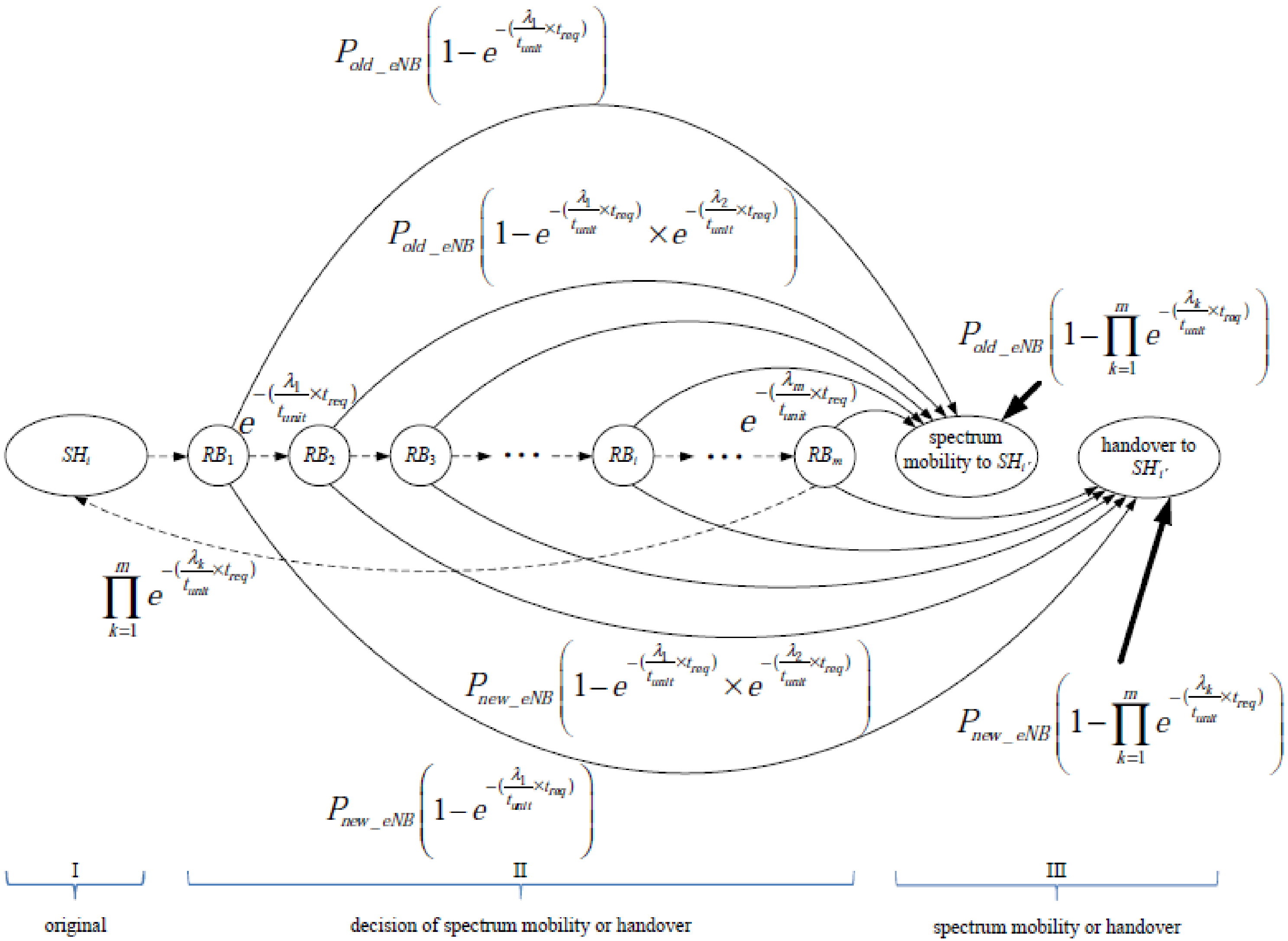
Theorem 1 *If there are j $(1 \leq i \leq j)$ spectrum holes, from SH_1 to SH_j, and N data packets, ranging from P_0 to P_{N-1}, to be transmitted from a SU_x to the serving eNB. The expected total transmission time, T_{TTT}, is*

$$T_{TTT} = \frac{1}{j}\sum_{i=1}^{j}((1 - P_u(SH_i, t_{req})) \times T_{L2H} + t_{req}), \text{ where } 1 \leq i \leq j, t_{req} = \frac{d_t}{R_i}. \tag{8}$$

Proof. Based on Lemma 2 and Lemma 3, the transmission time of one packet is calculated as $T_{old\_eNB} + T_{non-spectrum\ mobility}$. Using Eq. 5, the expected total transmission time is $T_{TTT} = \frac{1}{j}\sum_{i=1}^{j}\sum_{k=1}^{N-1} T_{one\_packet}$. Then, we have the following result.

$$\begin{aligned} T_{TTT} &= \frac{1}{j}\sum_{i=1}^{j}\sum_{k=0}^{N-1}[(1 - P_u(SH_i, t_{req})) \times (T_{L2H} + \frac{d_t}{R_i \times N}) + P_u(SH_i, t_{req}) \times \frac{d_t}{R_i \times N}] \\ &= \frac{1}{j}\sum_{i=1}^{j}(T_{L2H} + t_{req} - P_u(SH_i, t_{req}) \times T_{L2H}) \\ &= \frac{1}{j}\sum_{i=1}^{j}((1 - P_u(SH_i, t_{req})) \times T_{L2H} + t_{req}), \text{ where } 1 \leq i \leq j, t_{req} = \frac{d_t}{R_i}. \end{aligned}$$

Relation between resource blocks in the scenario Two.



Theorem 2 *If there are* j $(1 \leq i \leq j)$ *spectrum holes, from* SH_1 *to* SH_j*, and* N *data packets, ranging from* P_0 *to* P_{N-1}*, to be transmitted from a* SU_x *to the serving (old) eNB or the next (new) eNB. The expected total transmission time,* T_{TTT}*, is*

$$T_{TTT} = \frac{1}{j}\sum_{i=1}^{j}[(1 - P_u(SH_i, t_{req})) \times (T_{L2H} + P_{new\_eNB} \times T_{L3H}) + t_{req}],$$

where $1 \leq i \leq j, t_{req} = \frac{d_t}{R_i}$.

Proof. Based on Eq. 10 and lemmas 3, 4, and 5, it can be derived the final result as follows.

$$
\begin{aligned}
T_{TTT} &= \frac{1}{j}\sum_{i=1}^{j}\sum_{k=0}^{N-1}[(P_{old\_eNB} \times (1 - P_u(SH_i, t_{req})) \times (T_{L2H} + \frac{d_t}{R_i \times N})) \\
&\quad +(P_{new\_eNB} \times (1 - P_u(SH_i, t_{req})) \times (T_{L2H} + T_{L3H} + \frac{d_t}{R_i \times N})) \\
&\quad +(P_u(SH_i, t_{req}) \times \frac{d_t}{R_i \times N})] \\
&= \frac{1}{j}\sum_{i=1}^{j}[(P_{old\_eNB} \times (1 - P_u(SH_i, t_{req})) \times (T_{L2H} + t_{req})) \\
&\quad +(P_{new\_eNB} \times (1 - P_u(SH_i, t_{req})) \times (T_{L2H} + TL3H + t_{req}) \\
&\quad +P_u(SH_i, t_{req}) \times t_{req}] \\
&= \frac{1}{j}\sum_{i=1}^{j}[T_{L2H} + t_{req} - P_u(SH_i, t_{req}) \times T_{L2H} \\
&\quad +P_{new\_eNB} \times (1 - P_u(SH_i, t_{req})) \times T_{L3H} \\
&\quad +P_u(SH_i, t_{req}) \times t_{req}] \\
&= \frac{1}{j}\sum_{i=1}^{j}[(1 - P_u(SH_i, t_{req})) \times T_{L2H} + P_{new\_eNB} \times (1 - P_u(SH_i, t_{req})) \times T_{L3H} \\
&\quad +t_{req}] \\
&= \frac{1}{j}\sum_{i=1}^{j}[(1 - P_u(SH_i, t_{req})) \times (T_{L2H} + P_{new\_eNB} \times T_{L3H}) + t_{req}], \text{ where } 1 \le i \le j \text{ and } t_{req} = \frac{d_t}{R_i}.
\end{aligned}
$$

Theorem 3 *Assumed that the data size of a* SU_x *is* d_t *and the total transmission time of* d_t *is* T_{TTT}*, where* T_{TTT} *is derived from from Theorem 1 for the case of the* SU_x *is in the non-overlapped area and Theorem 2 for the case of the* SU_x *is in the overlapped area, the throughput* TP_1 *(the* SU_x *is in the non-overlapped area) and* TP_2 *(the* SU_x *is in the overlapped area), are derived as follows.*

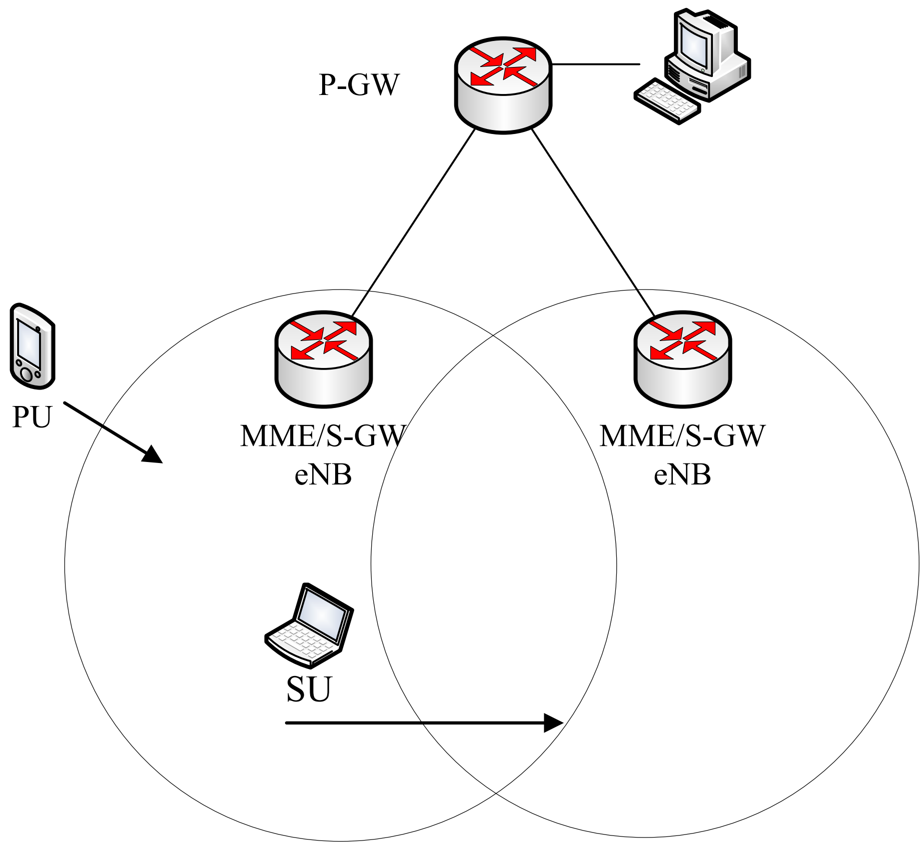
$$TP_1 = \frac{d_t \times j}{\sum_{i=1}^{j}((1 - P_u(SH_i)) \times T_{L2H} + t_{req})}, \qquad (14)$$

$$TP_2 = \frac{d_t \times j}{\sum_{i=1}^{j}((1 - P_i(SH_i, t_{req})) \times (T_{L2H} + P_{new\_eNB} \times T_{L3H}) + t_{req})}, \qquad (15)$$

where $1 \leq i \leq j, t_{req} = \frac{d_t}{R_i}$.

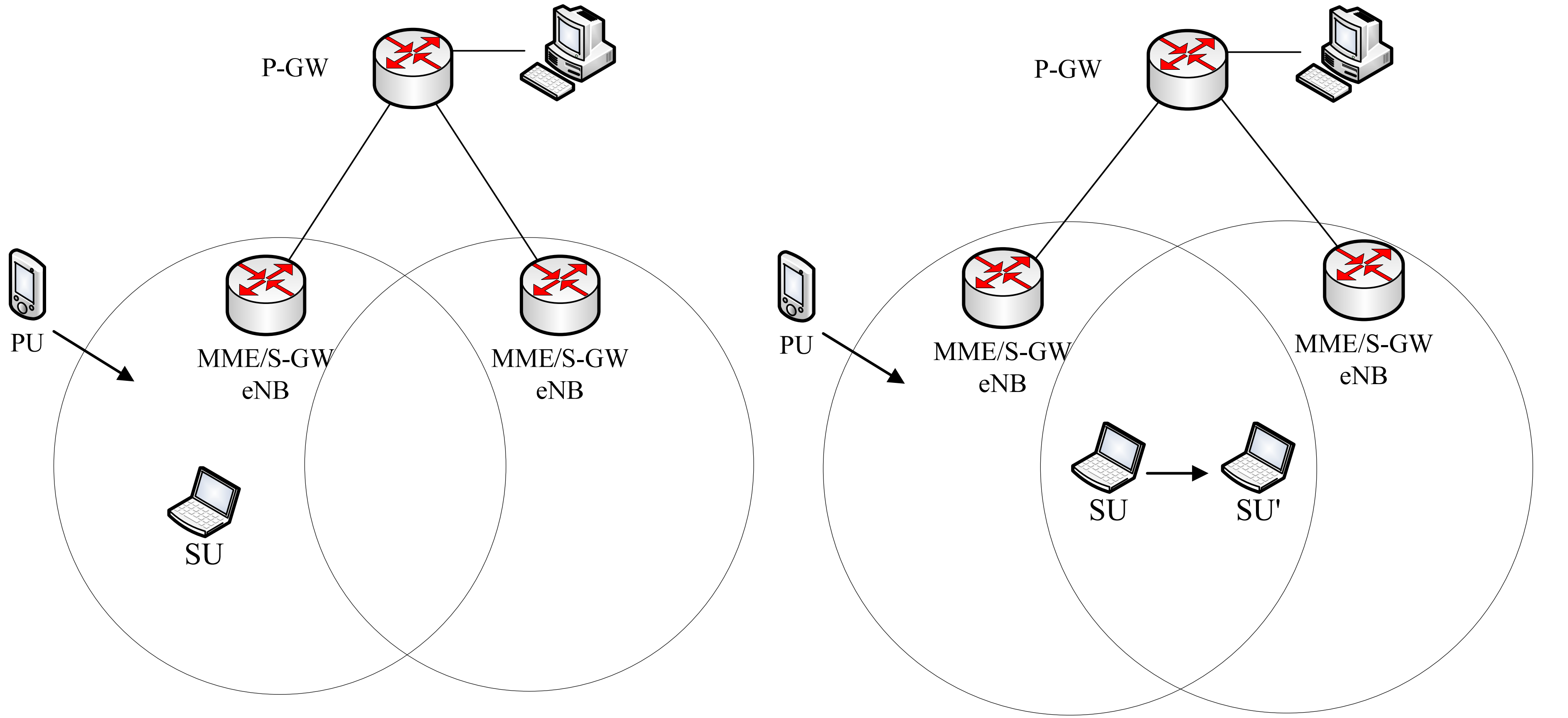
Simulation results

- Simulation environment
  - NS2 2.31, cognitive radio module, and EURANE module



Parameter	Value
BS transmission range	50 km
Network size	500×500 km
Secondary users speed	0-100 km/hr
Number secondary user	0-20
Spectrum sensing period	40 ms
Spectrum switching delay	10 ms
Handover delay	200 - 350 ms
Packet size	1500 bytes
Simulation time	100-1000 s

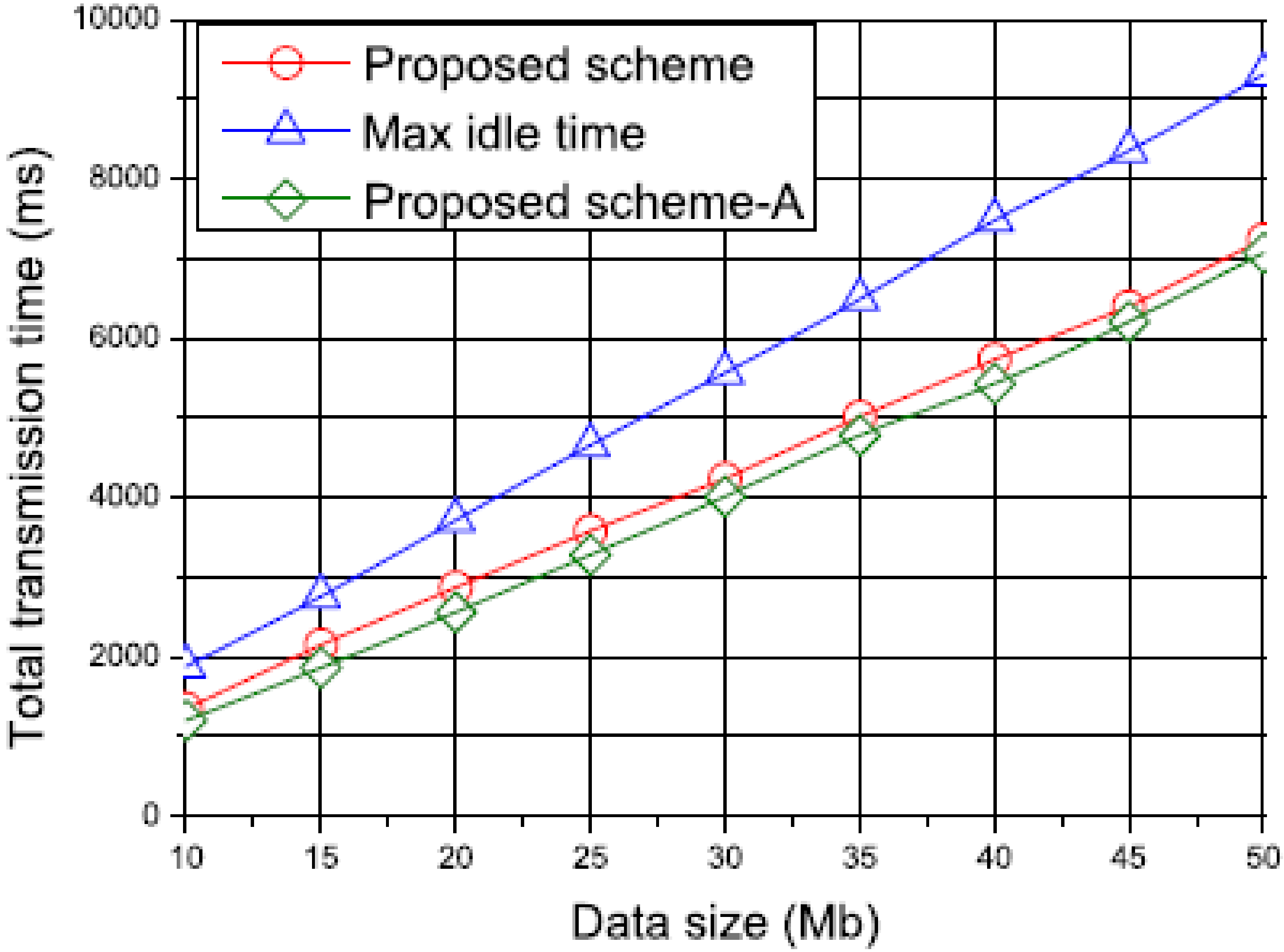
Simulation scenario



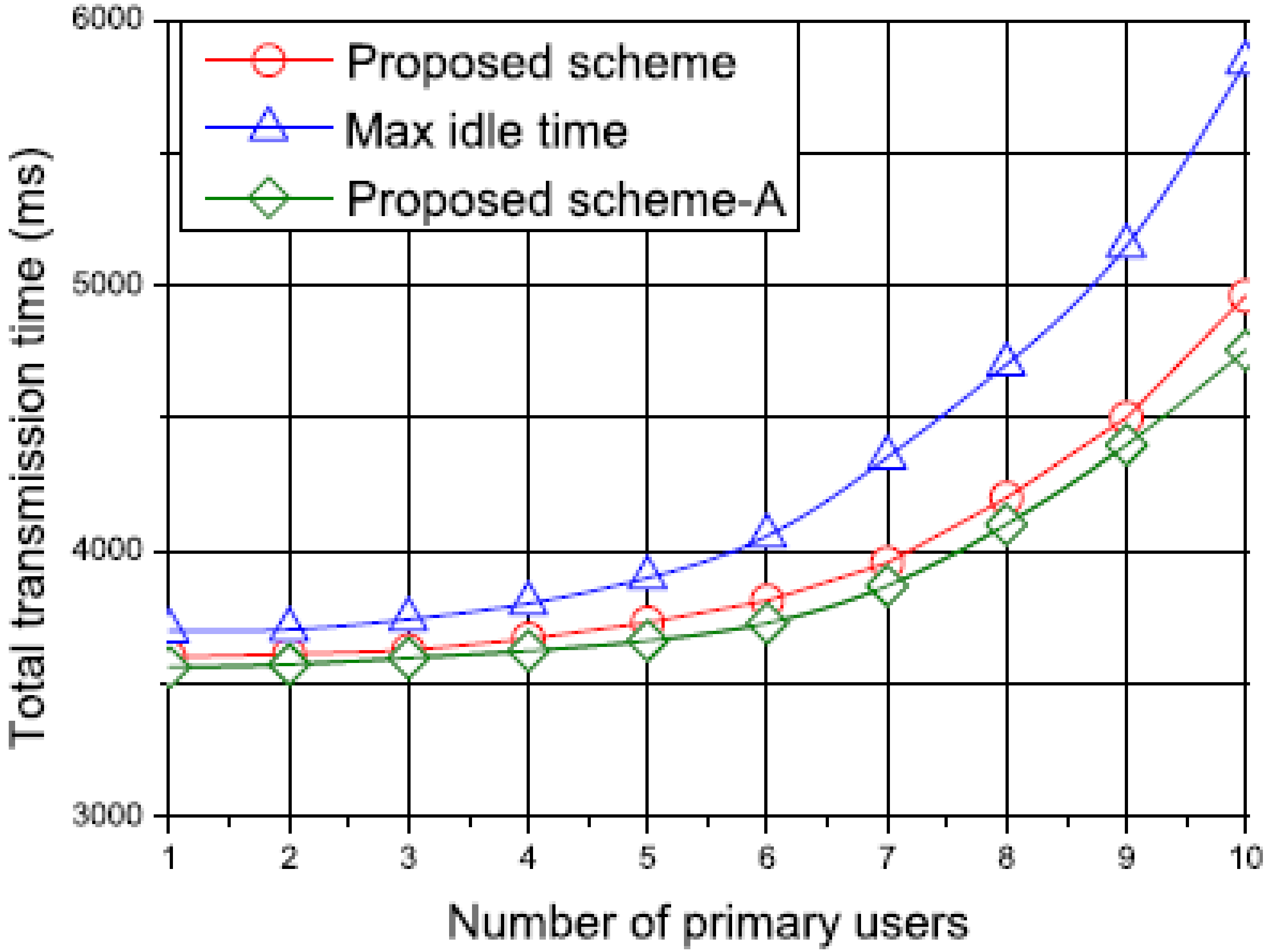
The performance metrics

- The *total transmission time* (TTT) is the time interval of the data transmission between a pair of a SU and a corresponding node, CN, through the old eNB or new eNB. The TTT is estimated from the first packet transmitted from CN until the final packet received by SU through the old eNB or new eNB.
- The *end-to-end delay* (EED) is the average delay time of every packets of a data which be transmitted from a SU to a CN by the old eNB or new eNB. If data sizes are same, the EED is large that represents the T_E of spectrum hole which be selected by SU is higher.
- The *throughput* (TP) is total number of data packets which can be transmitted and received between a pair of SU and CN per unit time.
- The *number of spectrum mobility* (NSM) is the total number of spectrum mobility during a data transmission between a pair of SU and CN.

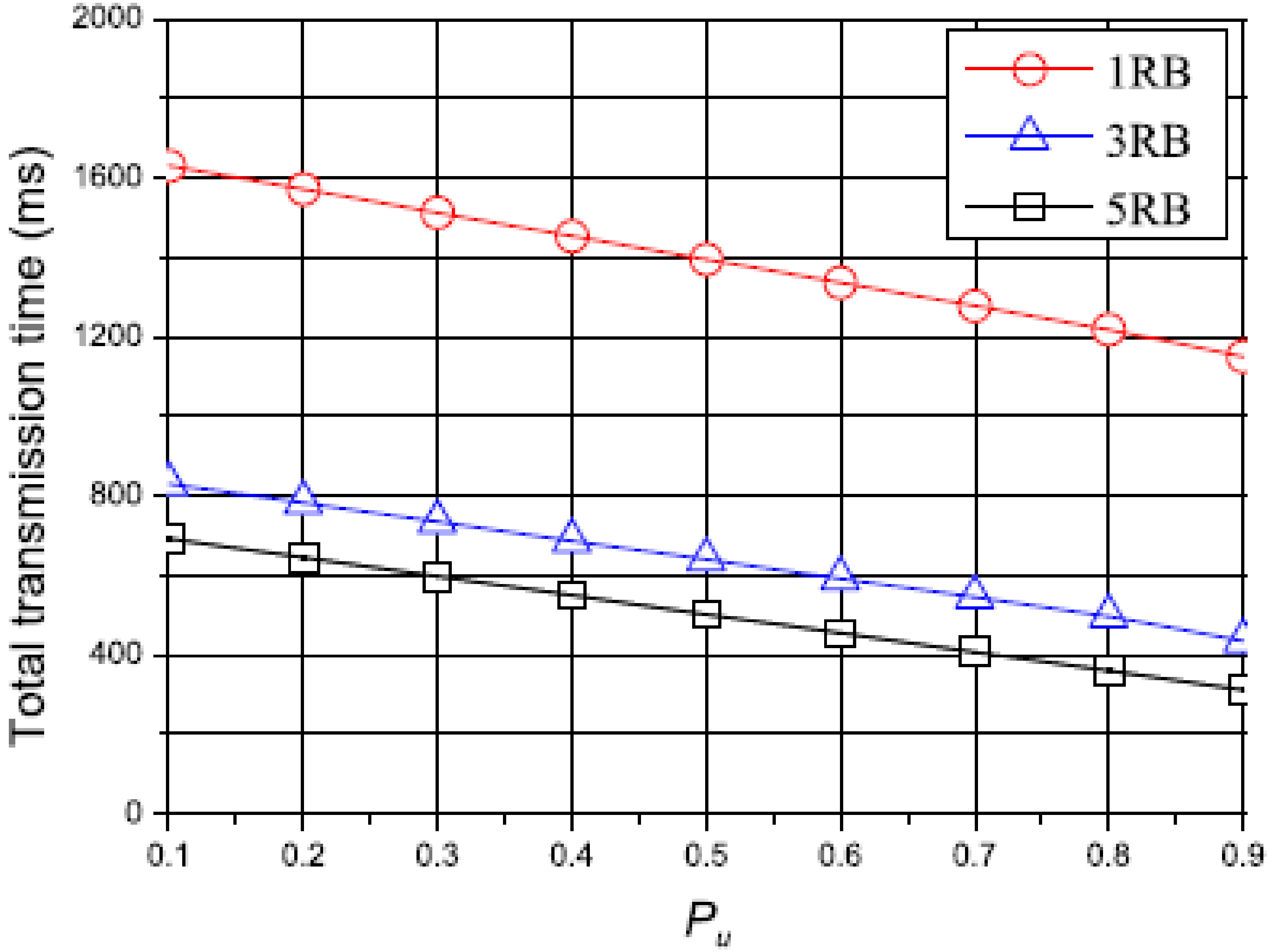
Total transmission time



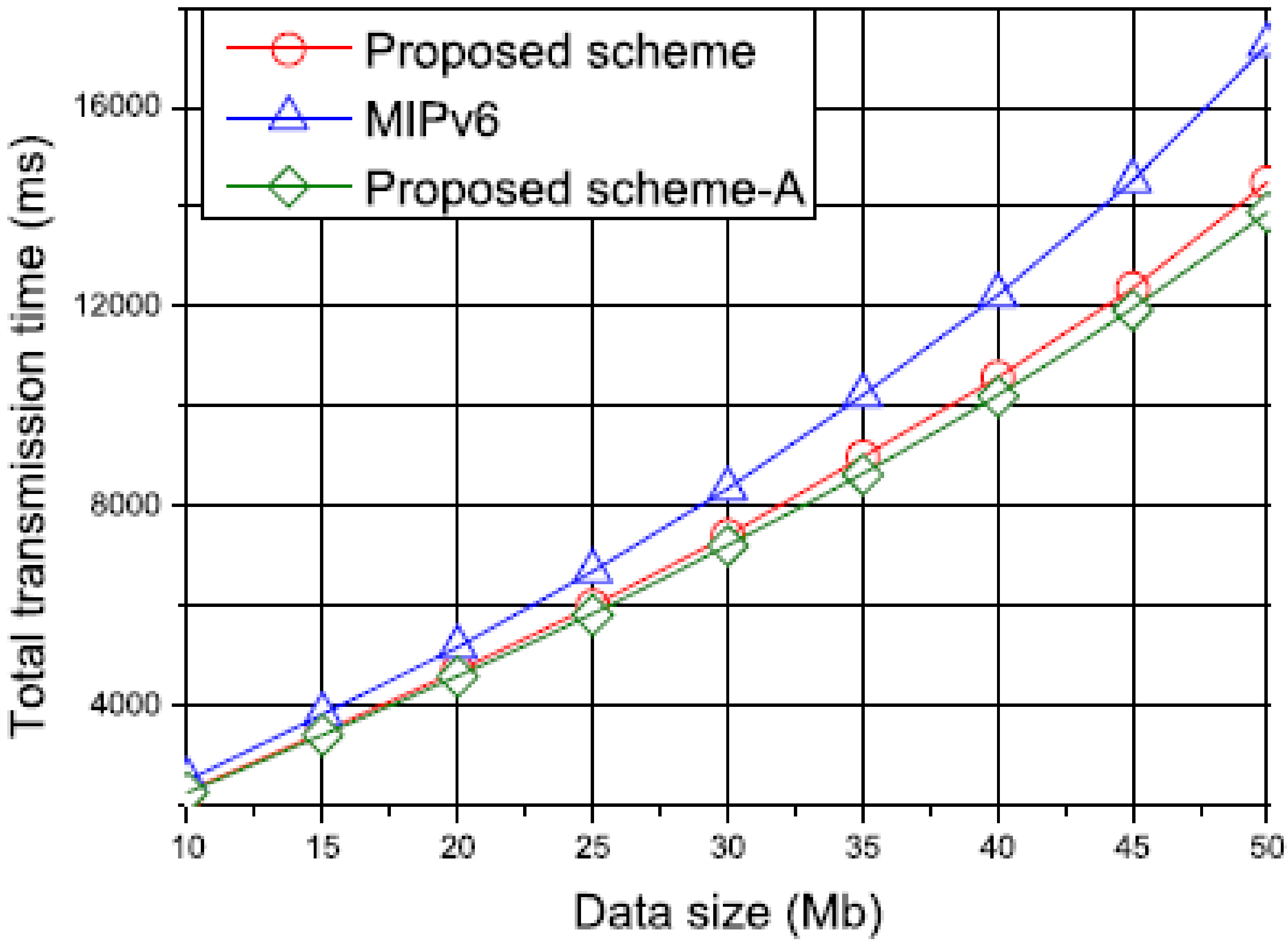
Total transmission time



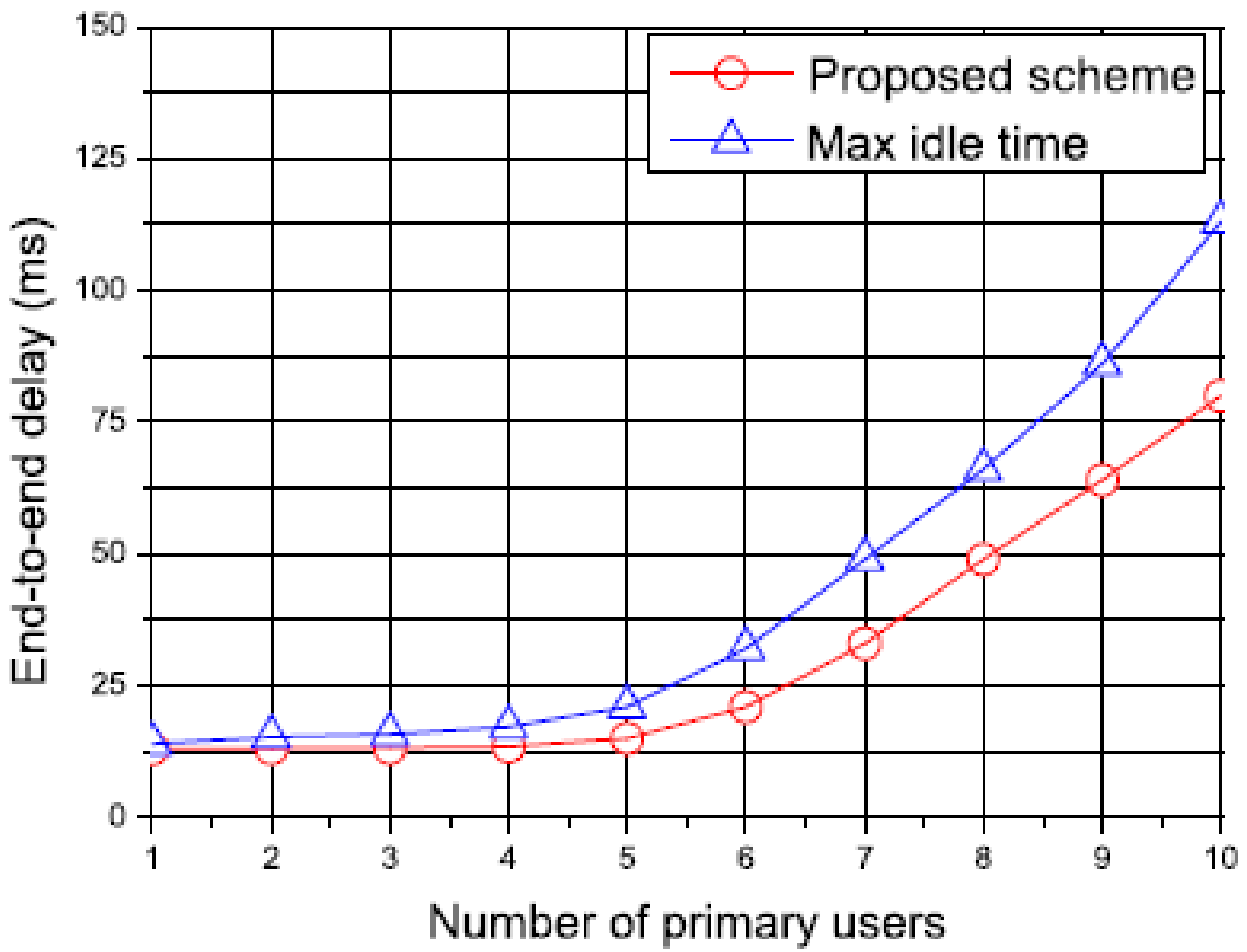
Total transmission time



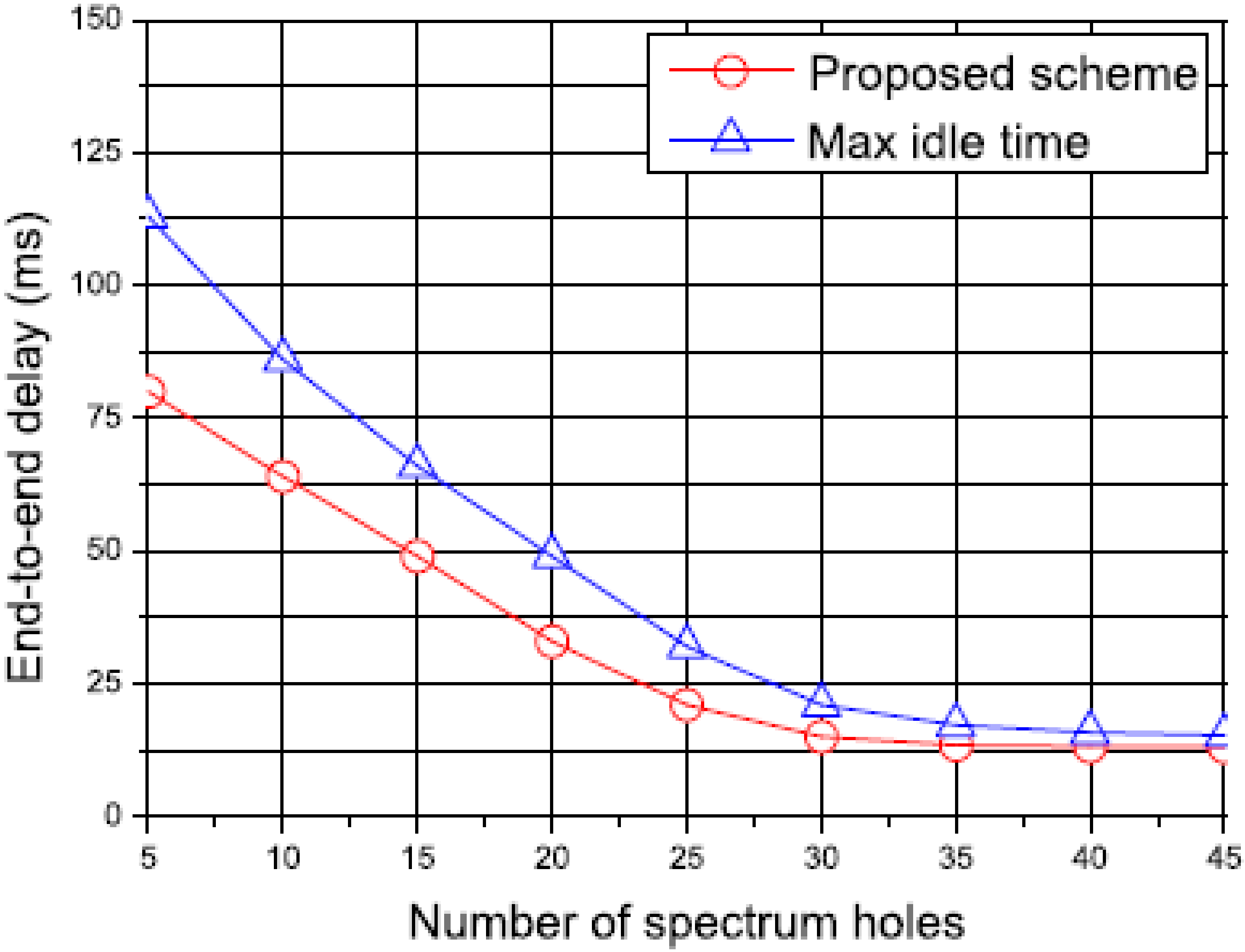
Total transmission time



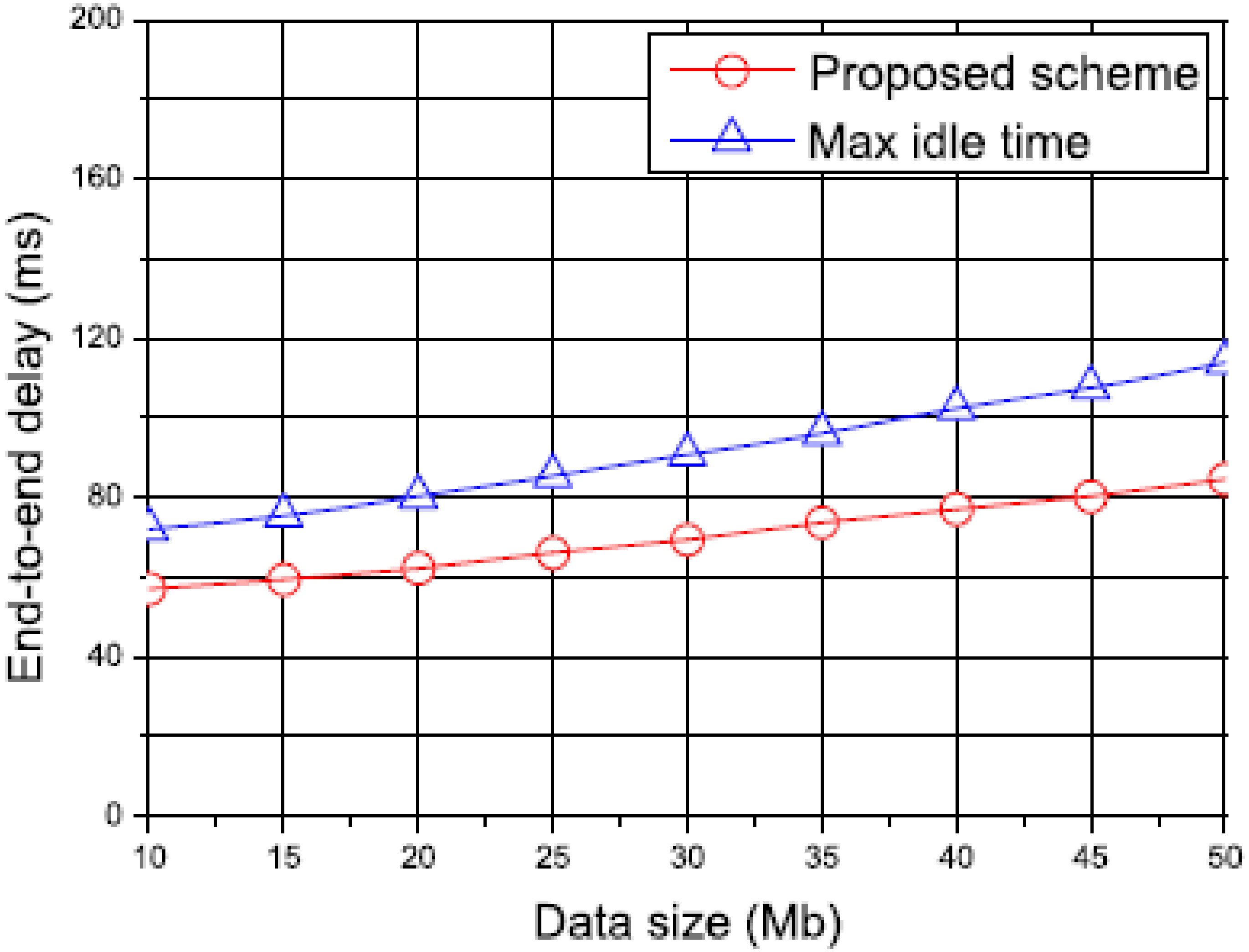
End-to-end delay



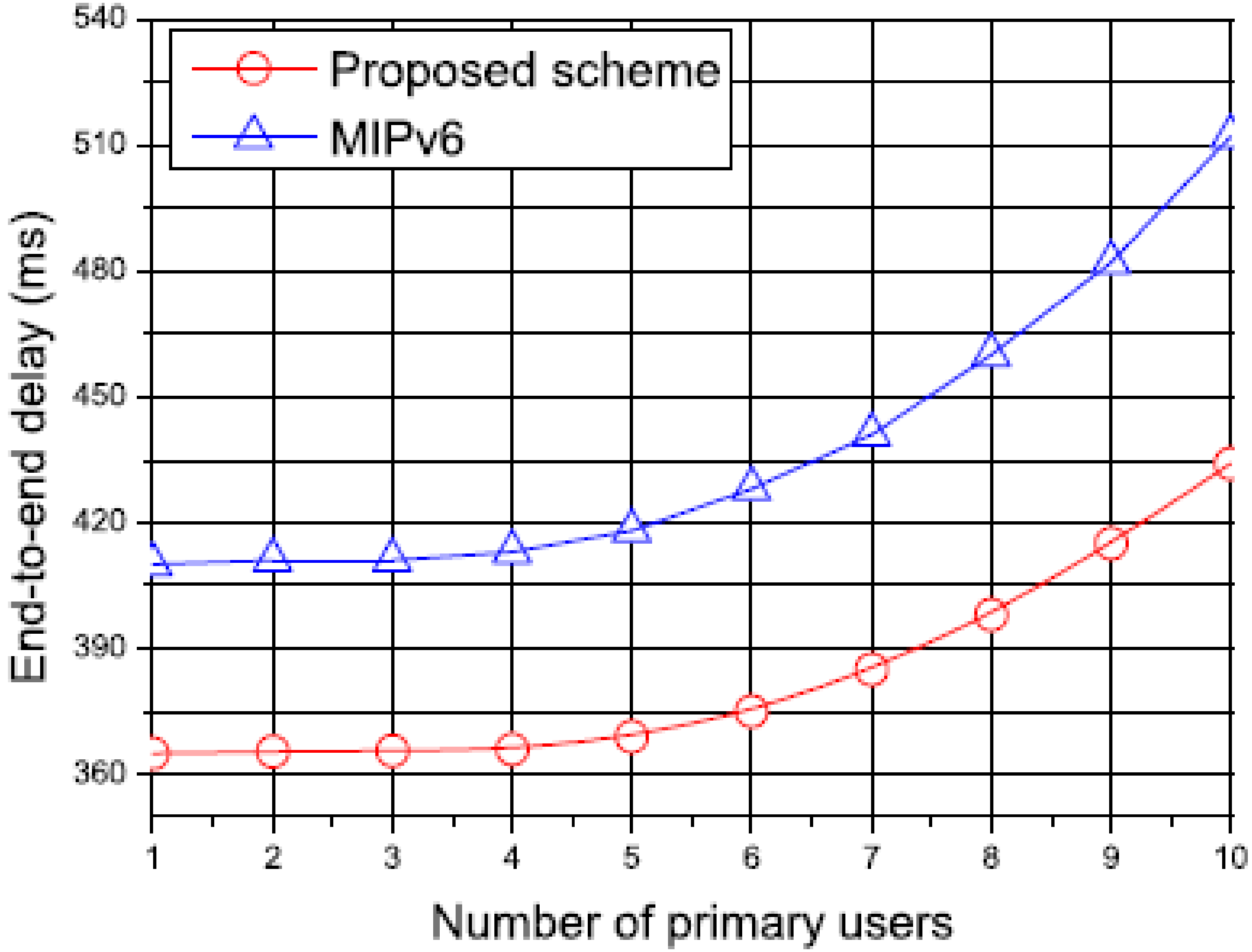
End-to-end delay



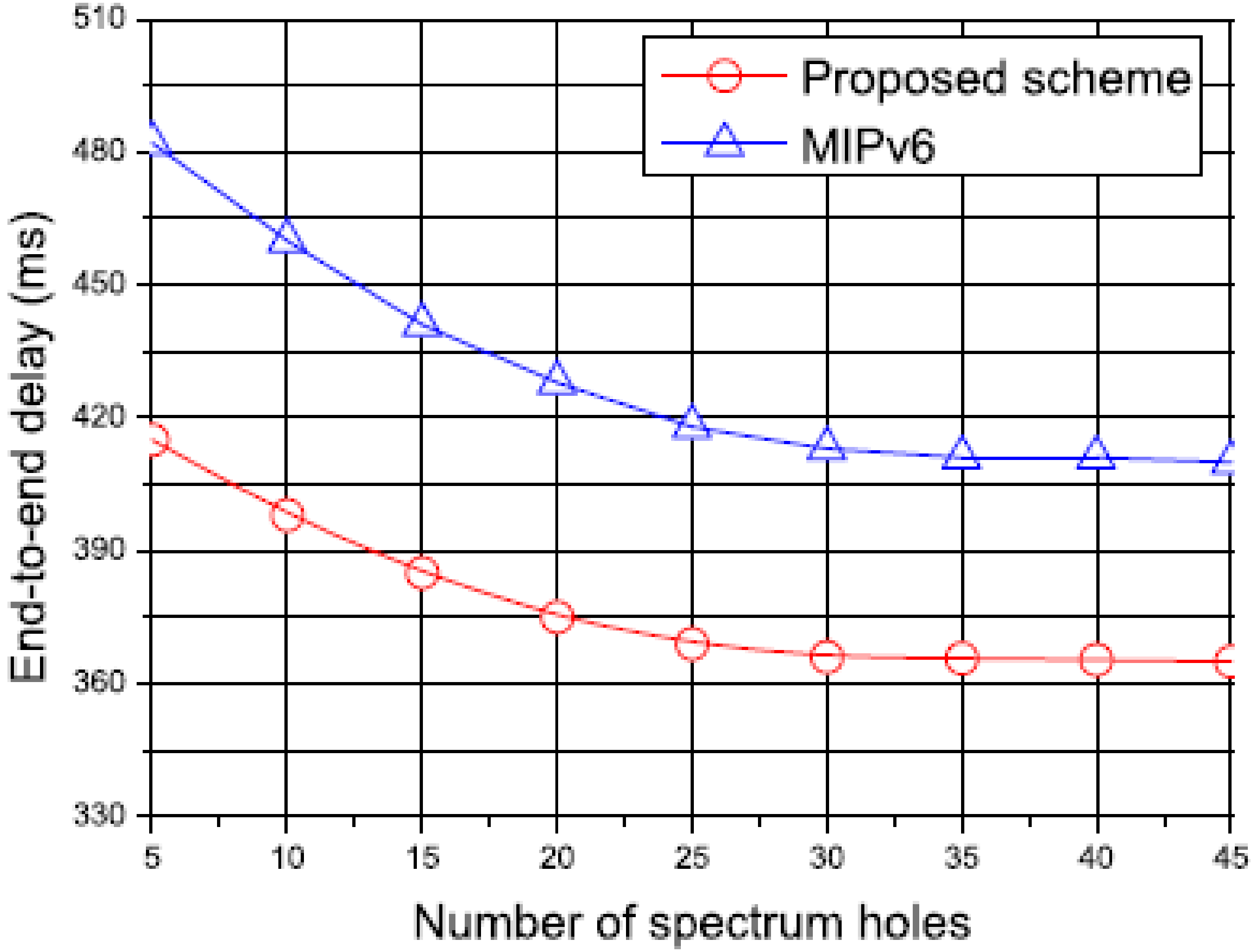
End-to-end delay



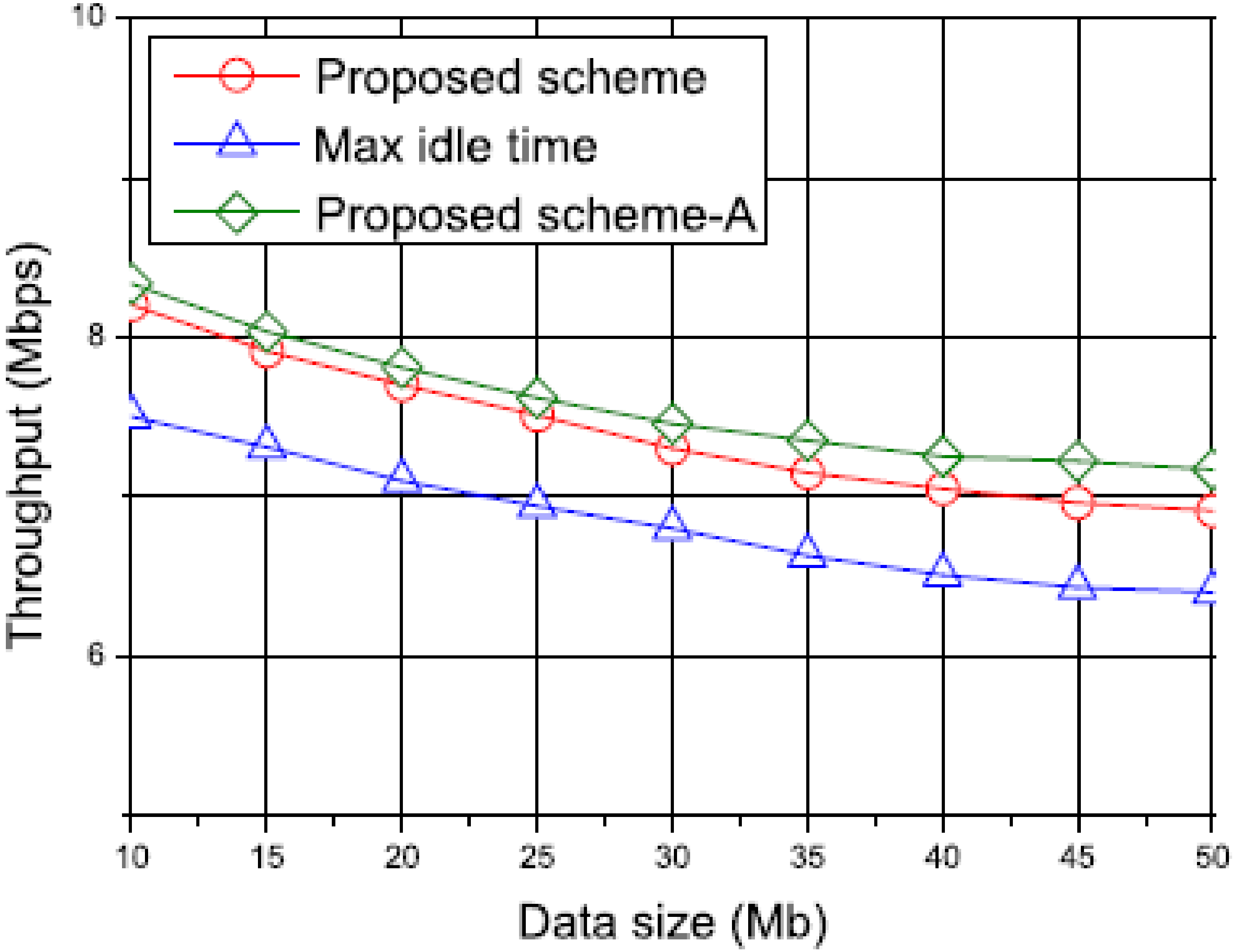
End-to-end delay



End-to-end delay

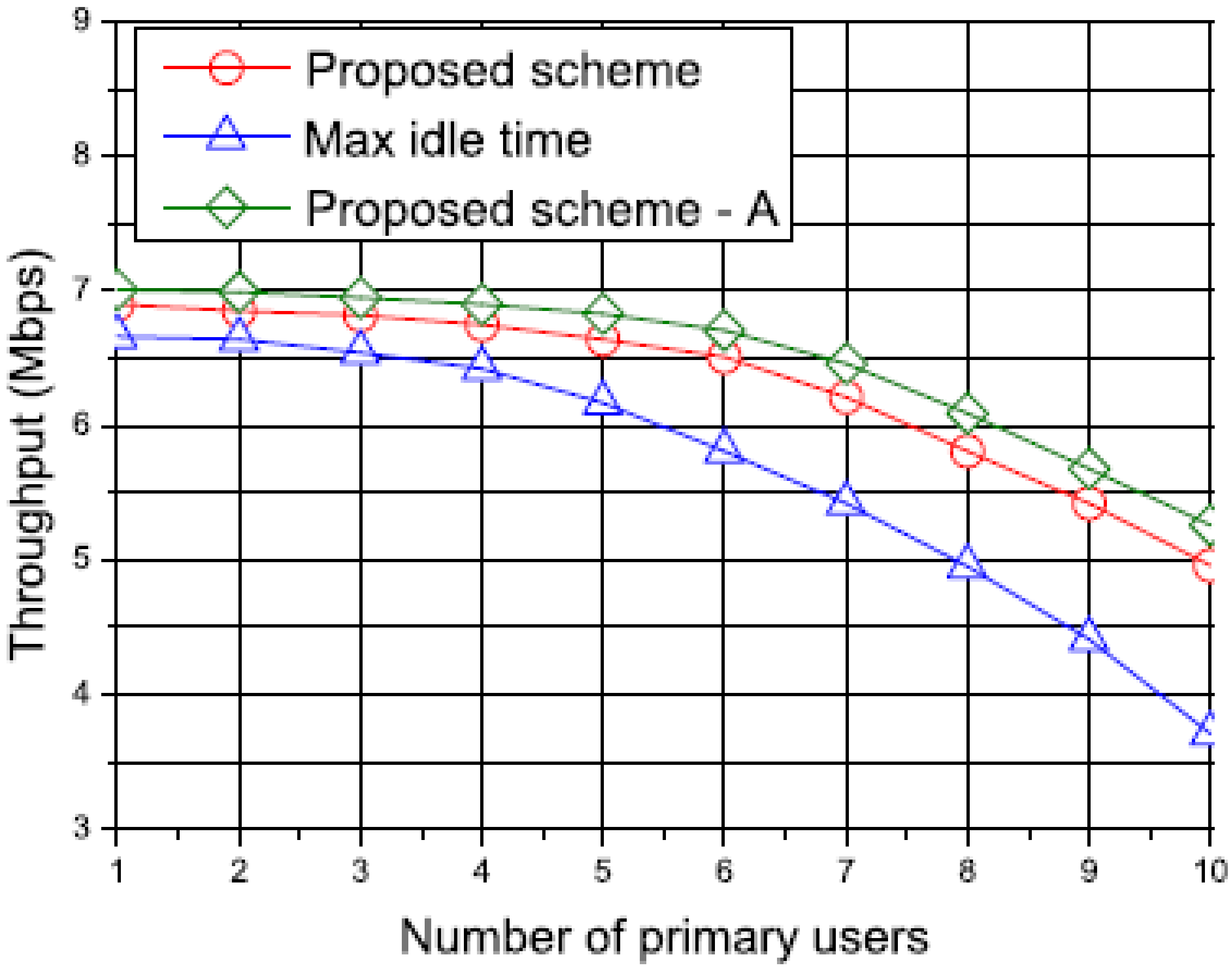


Throughput



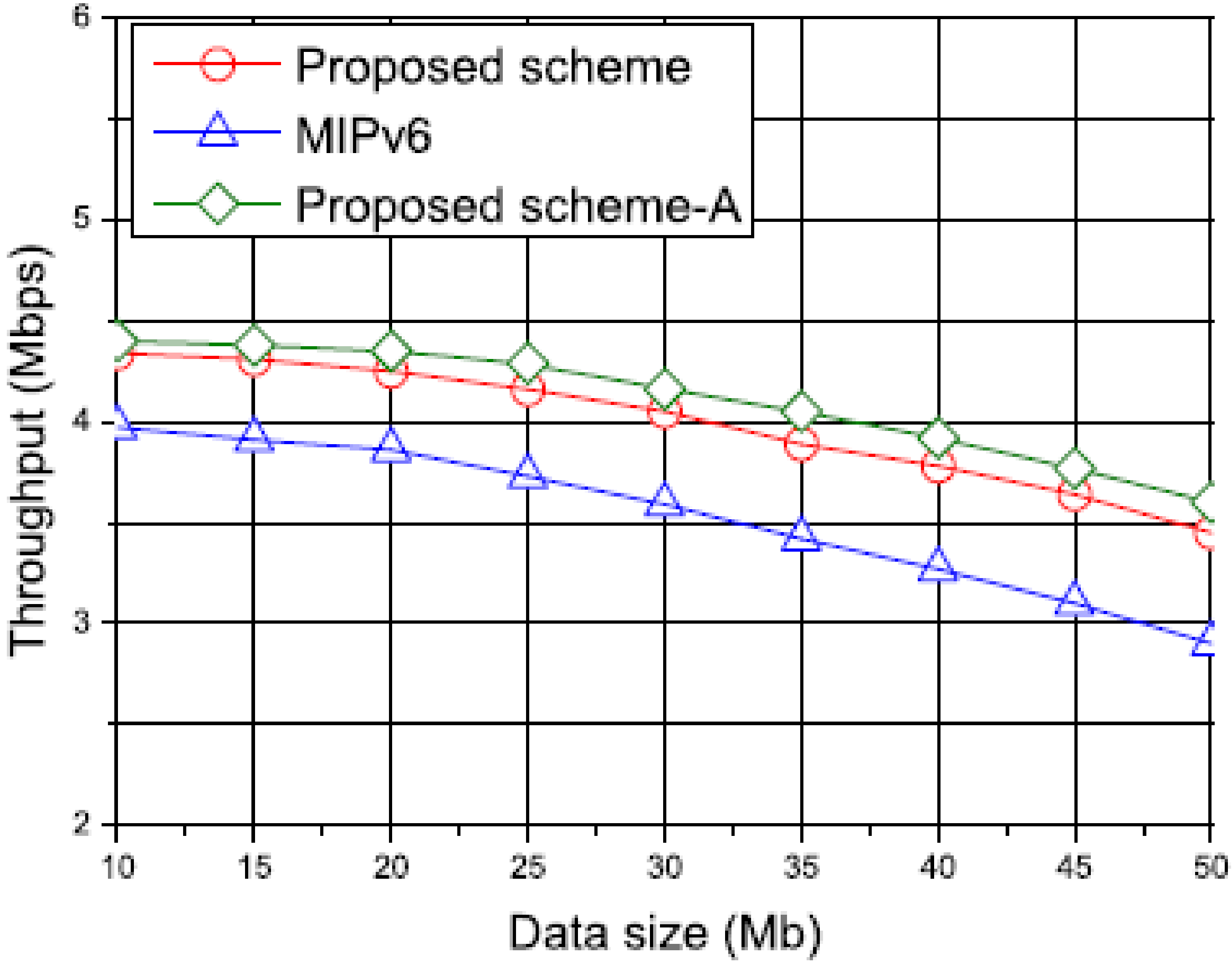
Proposed scheme
Max idle time
Proposed scheme-A
Throughput (Mbps)
10
8
6
10
15
20
25
30
35
40
45
50
Data size (Mb)

Throughput



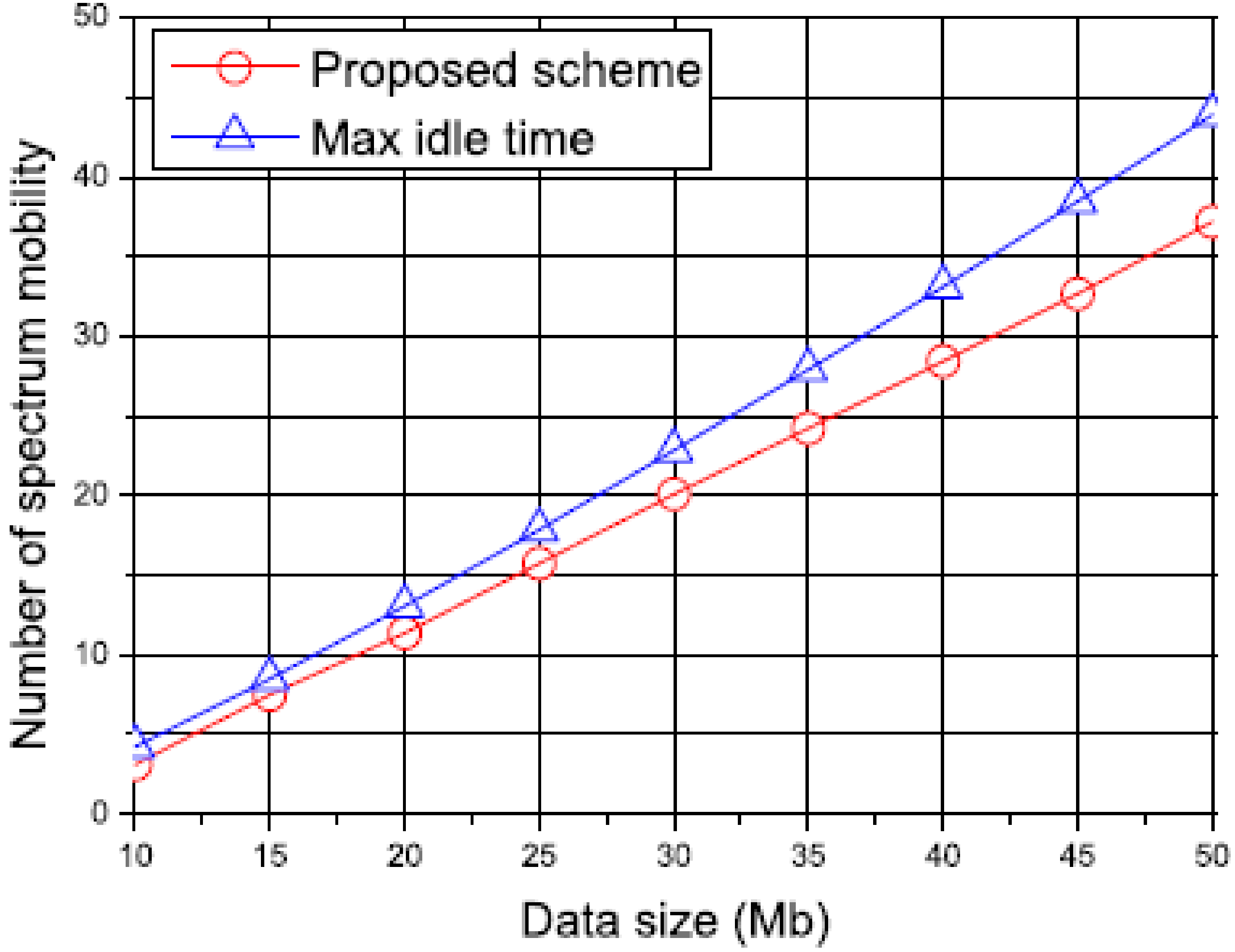
Proposed scheme
Max idle time
Proposed scheme - A
Throughput (Mbps)
3
4
5
6
7
8
9
1
2
3
4
5
6
7
8
9
10
Number of primary users

Throughput

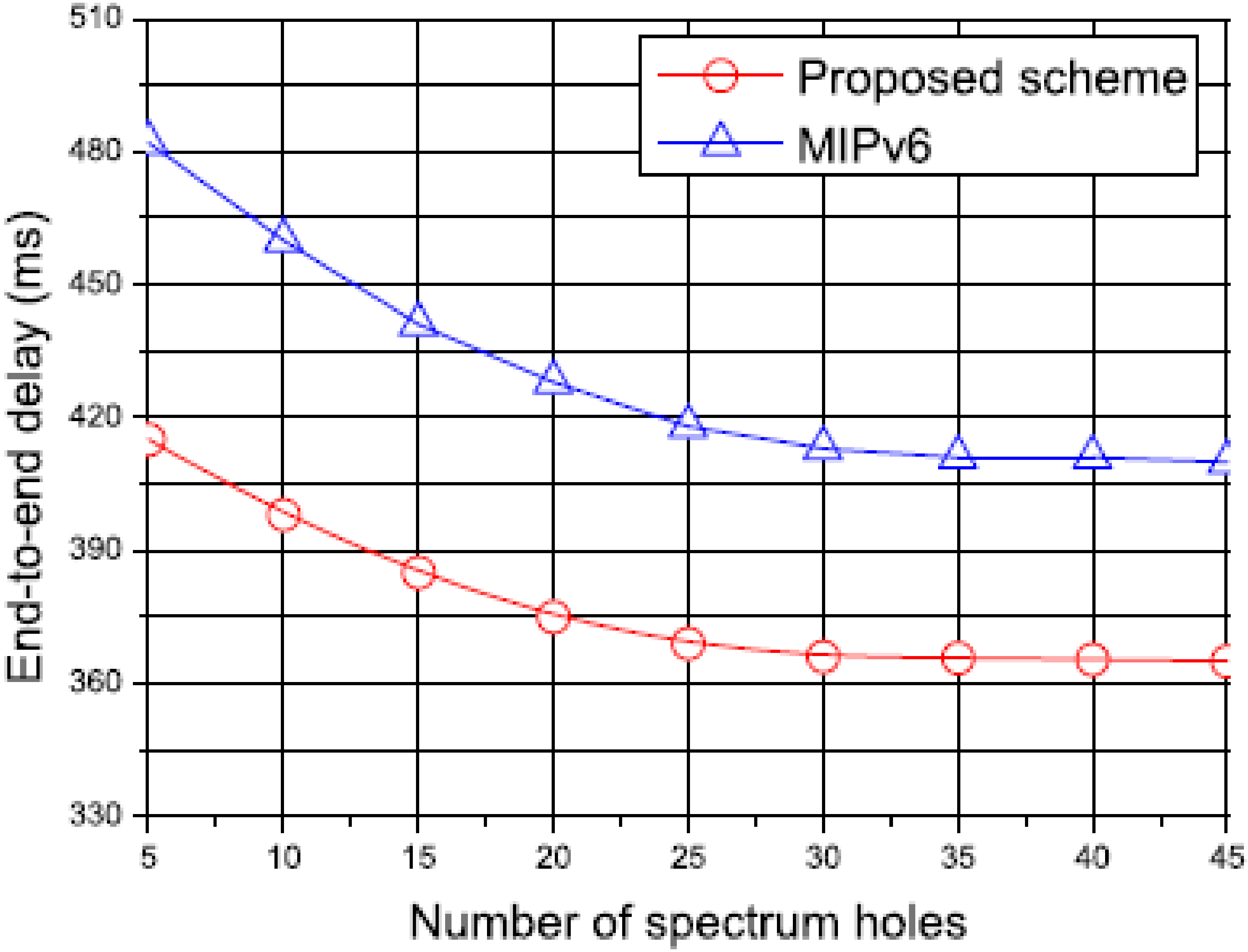


Proposed scheme
MIPv6
Proposed scheme-A
Throughput (Mbps)
Data size (Mb)
6
5
4
3
2
10
15
20
25
30
35
40
45
50

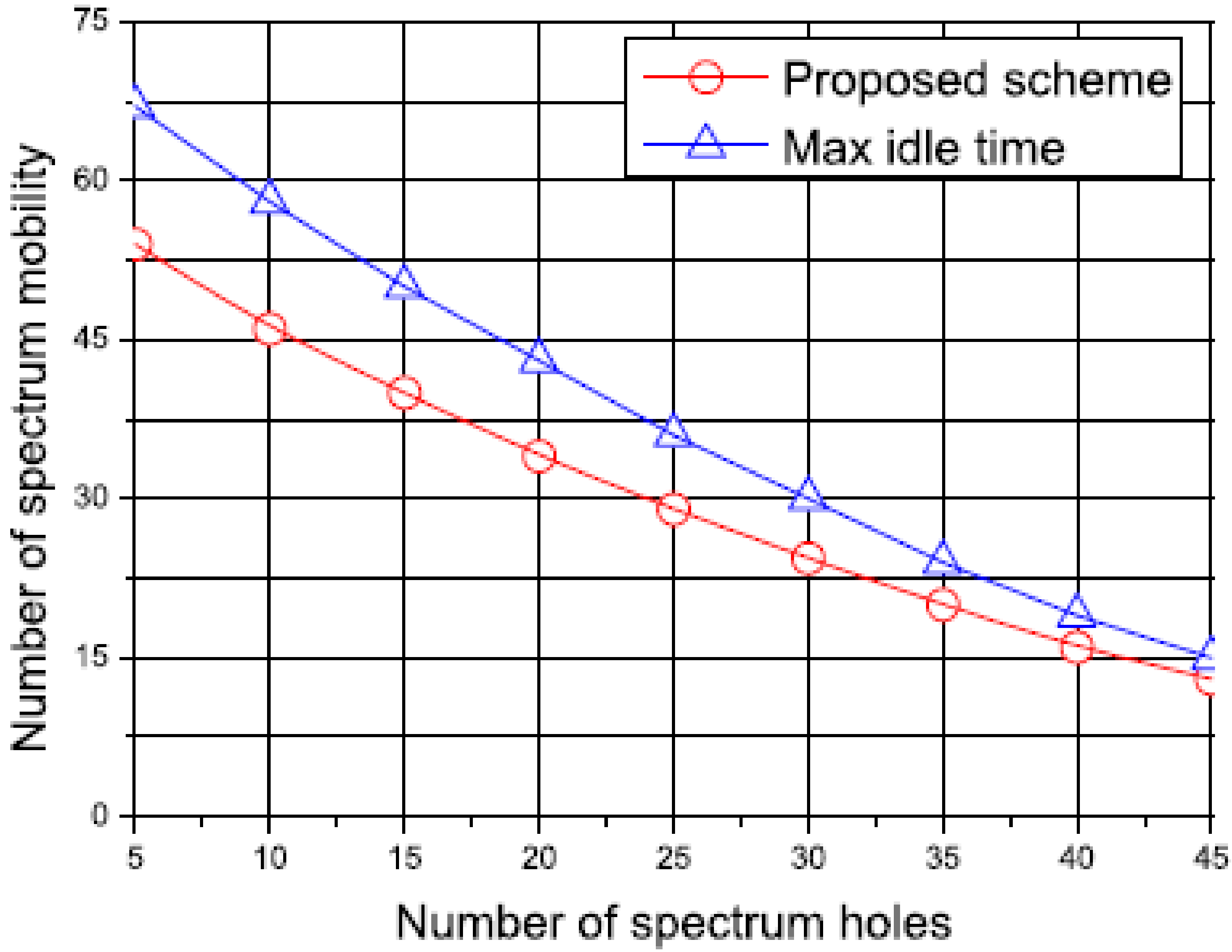
Number of spectrum mobility



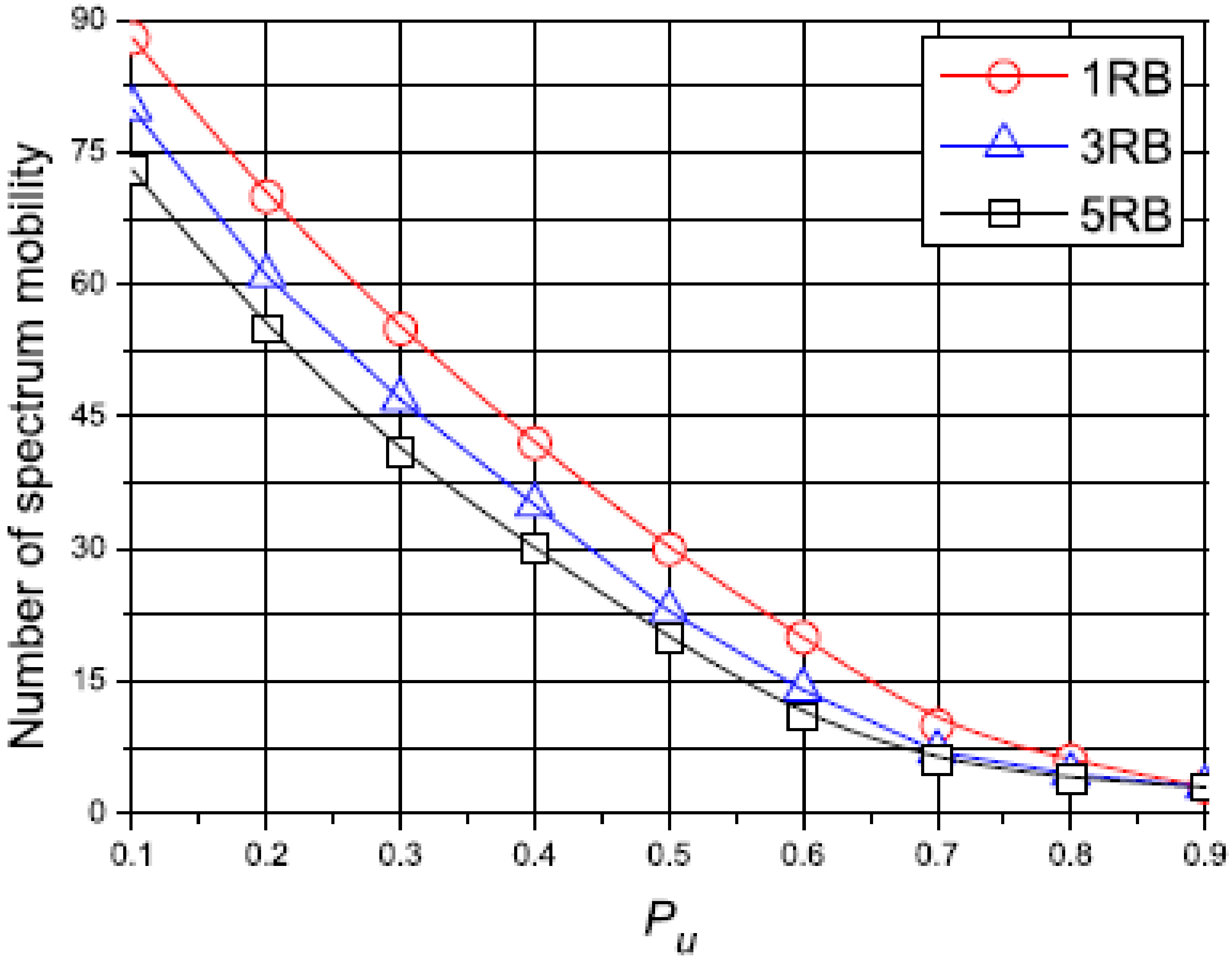
Number of spectrum mobility



Number of spectrum mobility



Number of spectrum mobility



A System Demo

Conclusion

- In this talk, a cross-layer protocol of spectrum mobility (layer-2) and handover (layer-3) in cognitive LTE networks is introduced for the "**green communications**".