A General Performance Evaluation Framework for Network Selection Strategies in 3G-WLAN Interworking Networks

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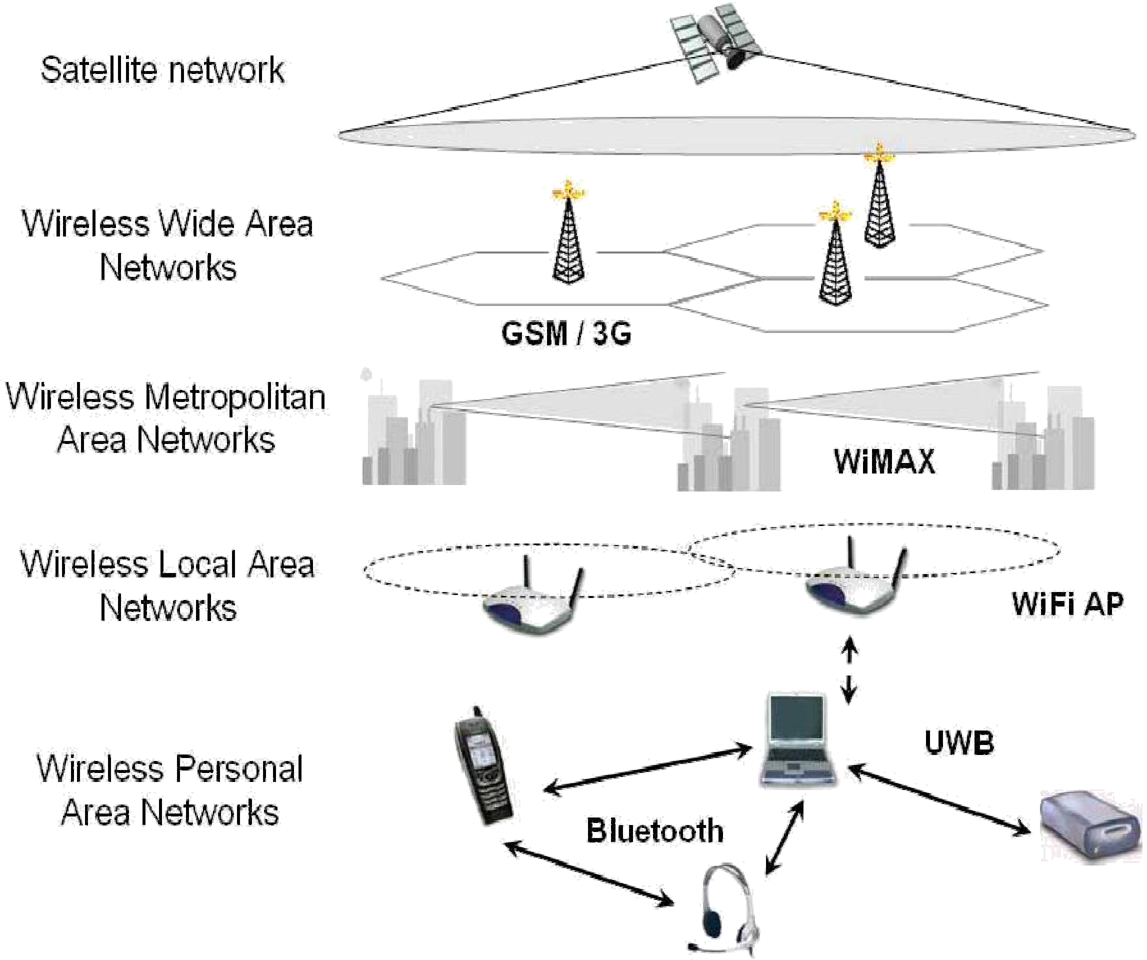
Outline

- 3G-WLAN Interworking Networks and Network Selection Strategies
- Models of Network Selection Strategies
- Derivation of Network Blocking Probabilities and Handover Rates
- Evaluation Results
- Conclusions

Heterogeneous wireless networks

- Users are able to use a wide range of wireless networks, often with multiple networks available at the same time.



Heterogeneous wireless networks

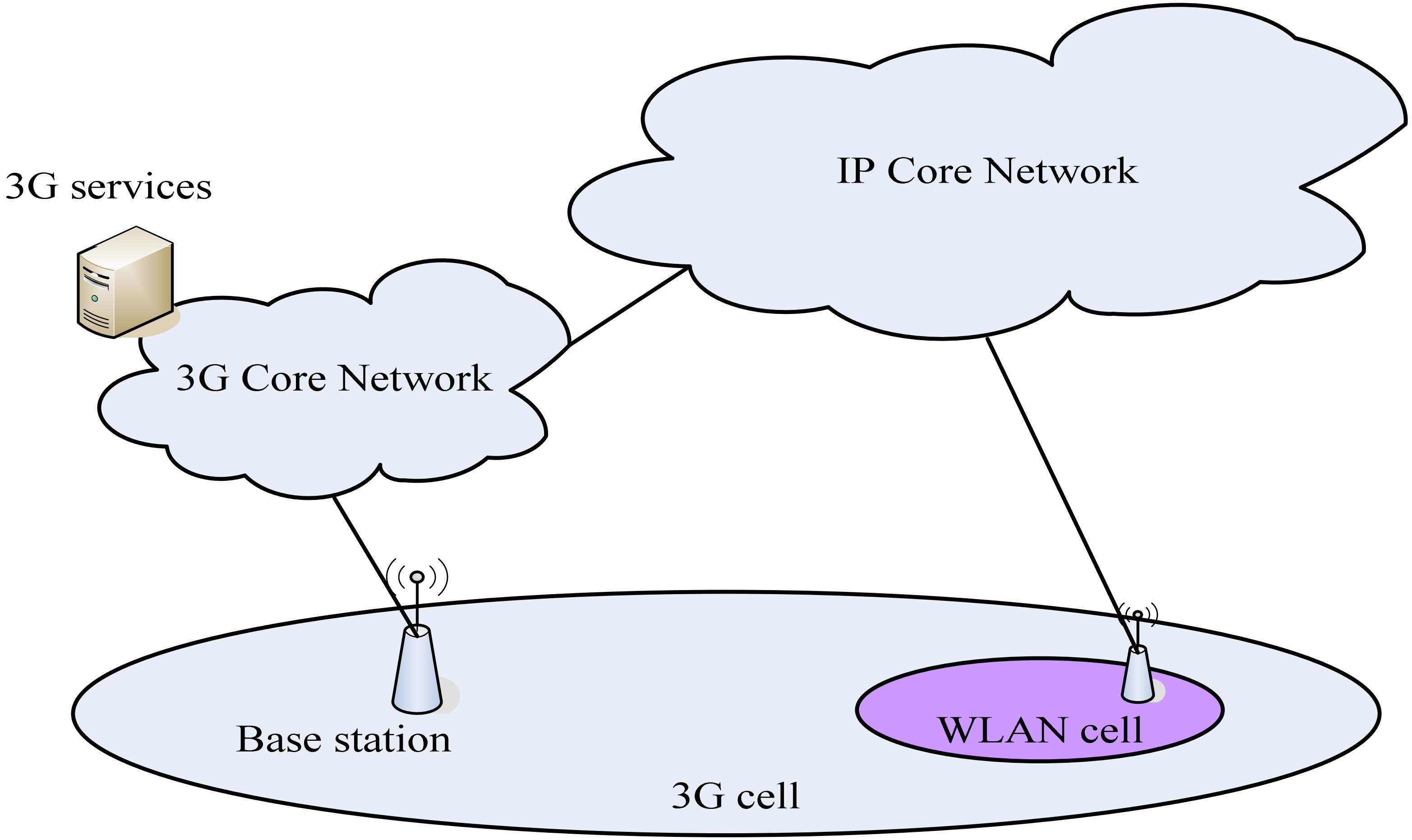
- Heterogeneous wireless networks have complementary characteristics such as data rate and coverage, e.g.

	Coverage Area	Data Rate
3G	~ 1 – 2 km	2 Mbps (3G)
WLAN	~ 100 – 200 m	54 Mbps (802.11a)
Bluetooth	~ 10m	24 Mbps (version 3.0)

- Therefore, it is envisioned that next-generation wireless communications will focus on the integration of these heterogeneous networks.

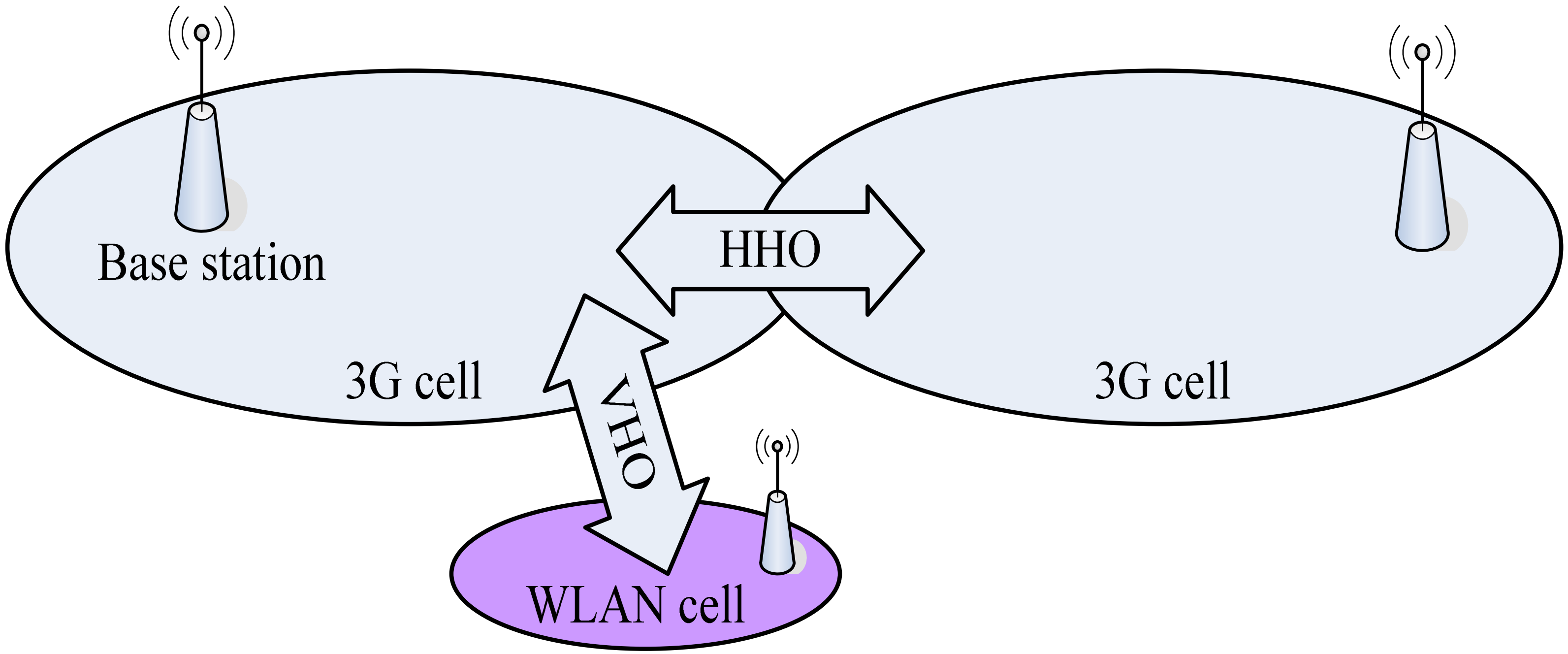
3G-WLAN interworking architecture

- It is becoming necessary to integrate wireless LANs (WLANs) and 3G cellular networks, to form 3G-WLAN interworking networks.



Horizontal and vertical handovers

- In heterogeneous wireless networks, a mobile node may perform handovers during its communications:
  - horizontal handover (HHO): a mobile node moves across cells that use the same type of access technology.
  - vertical handover (VHO): the movement between different types of wireless networks.



Handover decision of HHO and VHO

- Before a mobile node performs either handover it must:
  - collect information to confirm the need for a handover, and
  - decide whether to perform the handover.
- For a HHO, the handover criterion is usually just the signal strength received by the mobile node.
- For a VHO, various handover criteria can be taken into account when making a handover decision e.g.:
  - cost of service: cost is a major consideration, and could be sometimes be the decisive factor.
  - network conditions: network-related parameters such as bandwidth and network latency.
  - mobile node conditions: the node's dynamic attributes such as mobility pattern, account balance and power consumption.
  - user preference: a user may have preference for one type of network over another.

Network selection strategies

- To facilitate the above evaluation process, mathematical expressions are introduced: network selection strategies (NSSs).

- A number of NSSs have been generally based on multiple a (MADM) theory.

- A typi xample is simple strategy
  - each ne rk is ass ted with a the weigh d sum o the hand

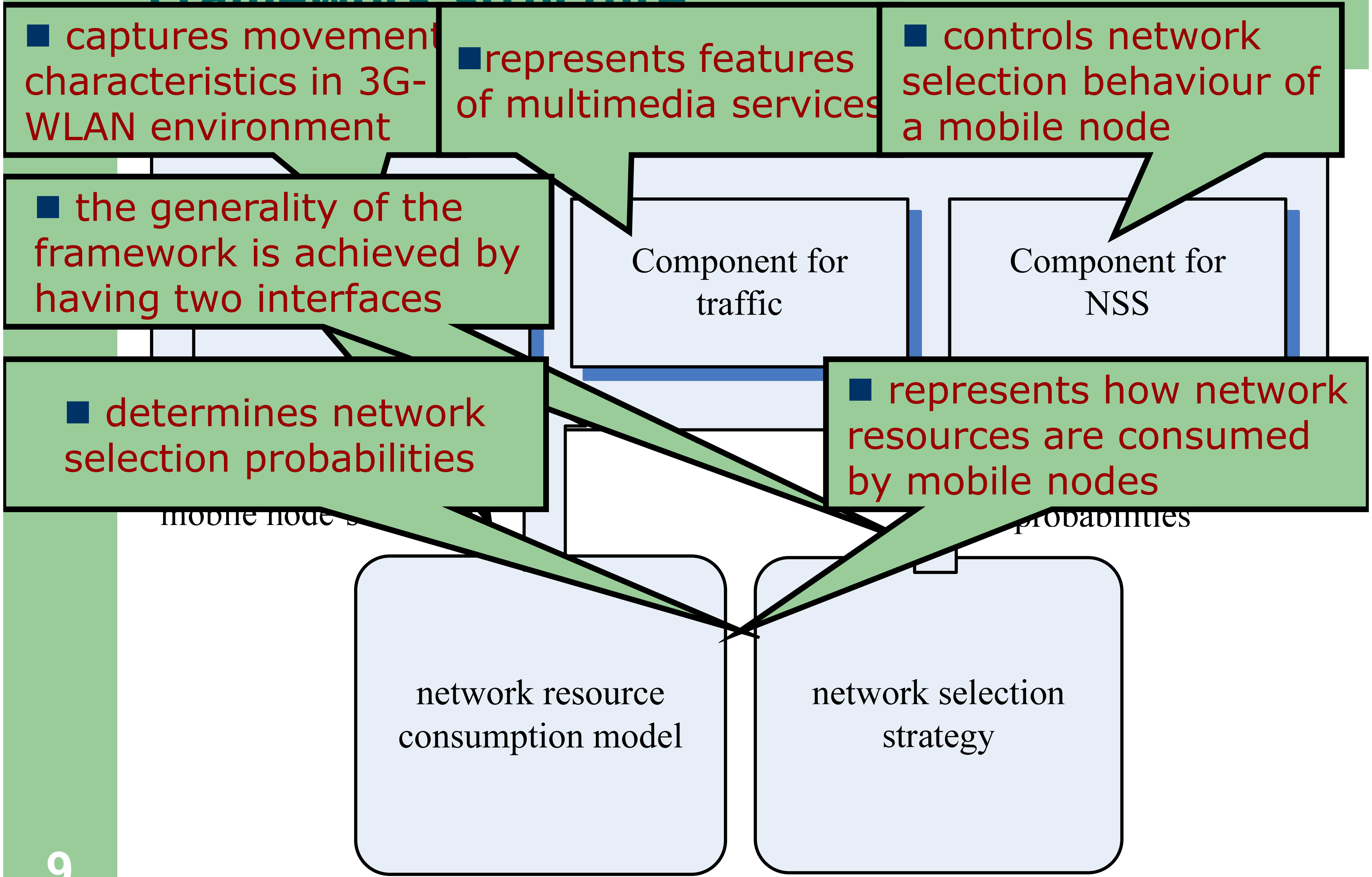
- there are N attributes

- weight of attr

- normalised value of attribute j of network i, where M is the number of candidate networks.
- this is used to cancel the effect of the unit of different attributes

- $P_i = \sum_{j=1}^{N} w_j * r_{ij}$, where $r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{M} x_{ij}}$

Framework structure



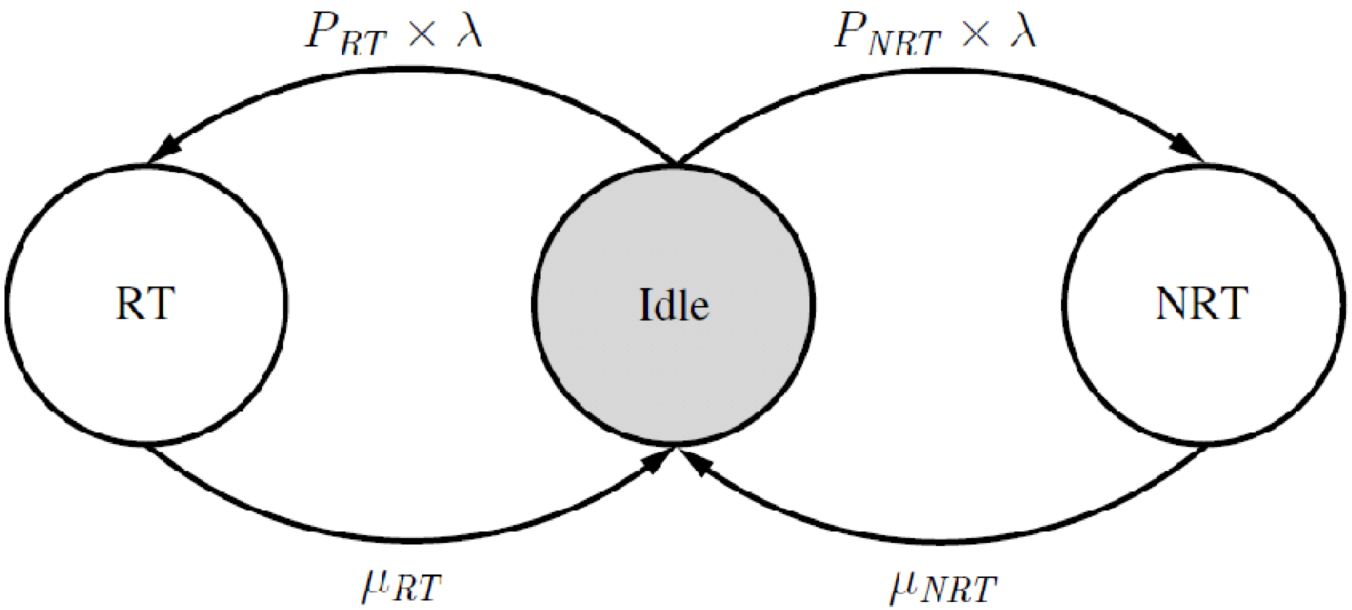
Traffic model

- The traffic model of a mobile node is modelled in the session model, which includes two parameters: session arrival rate and session duration.
- Field data suggests that the statistical session duration of multi-type-services has a coefficient of variation (CoV) larger than one.
- To capture this feature, we use the hyper-exponential distribution (HED) to model the session duration. A two-phase HED is used in this work, where one phase represents non-real time (NRT) sessions and the other represents real time (RT) sessions.

Traffic model

- As for session arrival rate, the general consensus that the session arrival is a Poisson process is followed.

- The traffic model is constructed as a combination of two ON-OFF sources:



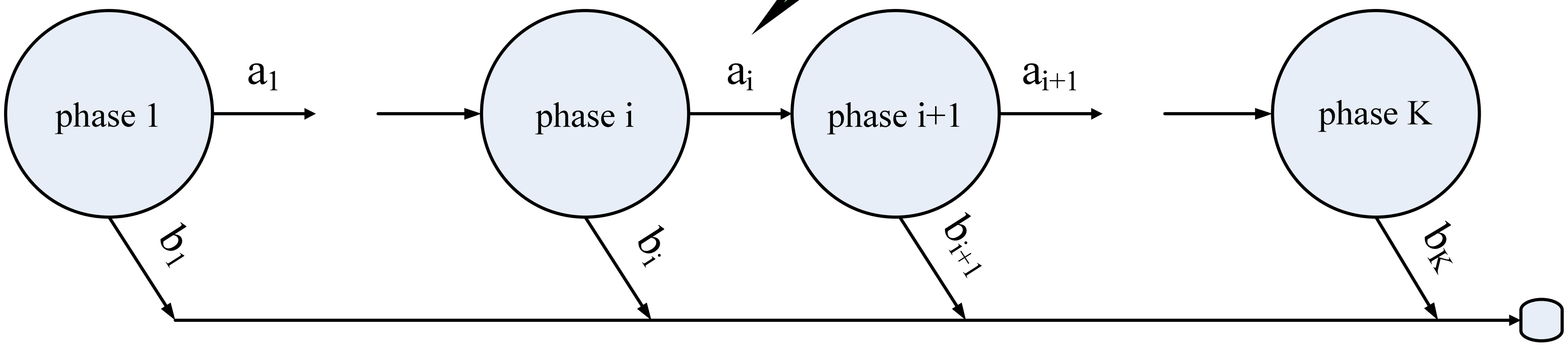
Mobility model

- In 3G-WLAN interworking networks, a 3G cellular cell is generally overlaid with one or more WLAN cells.

- The mobility model characterises a node's residence time in:
  - both the whole 3G-WLAN comp
  - and different radio access techn

- it can approximate any probability distribution arbitrarily closely

- Thus a Coxian distribution is used e mobility model:
  - a K-phase Coxian structure is mposed of a series of K exponentially distributed state nd an absorbing state.



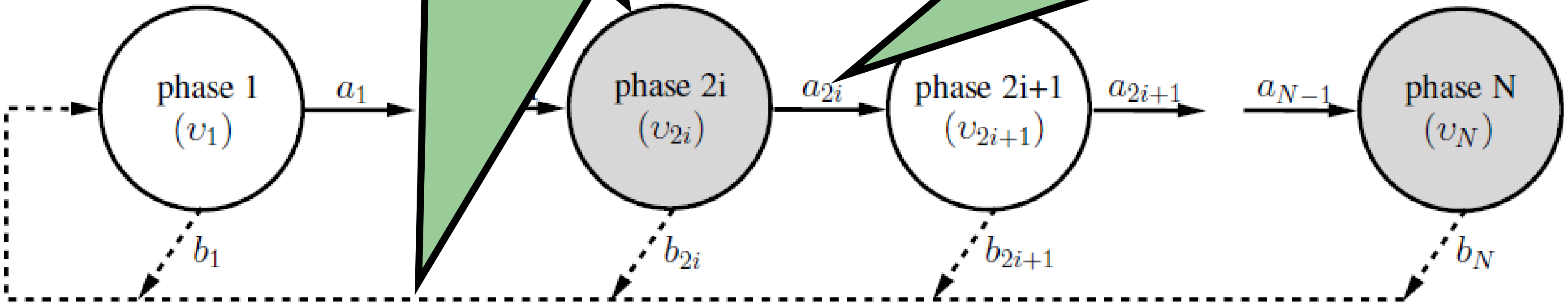
Mobility model

■ even phases: 3G-WLAN

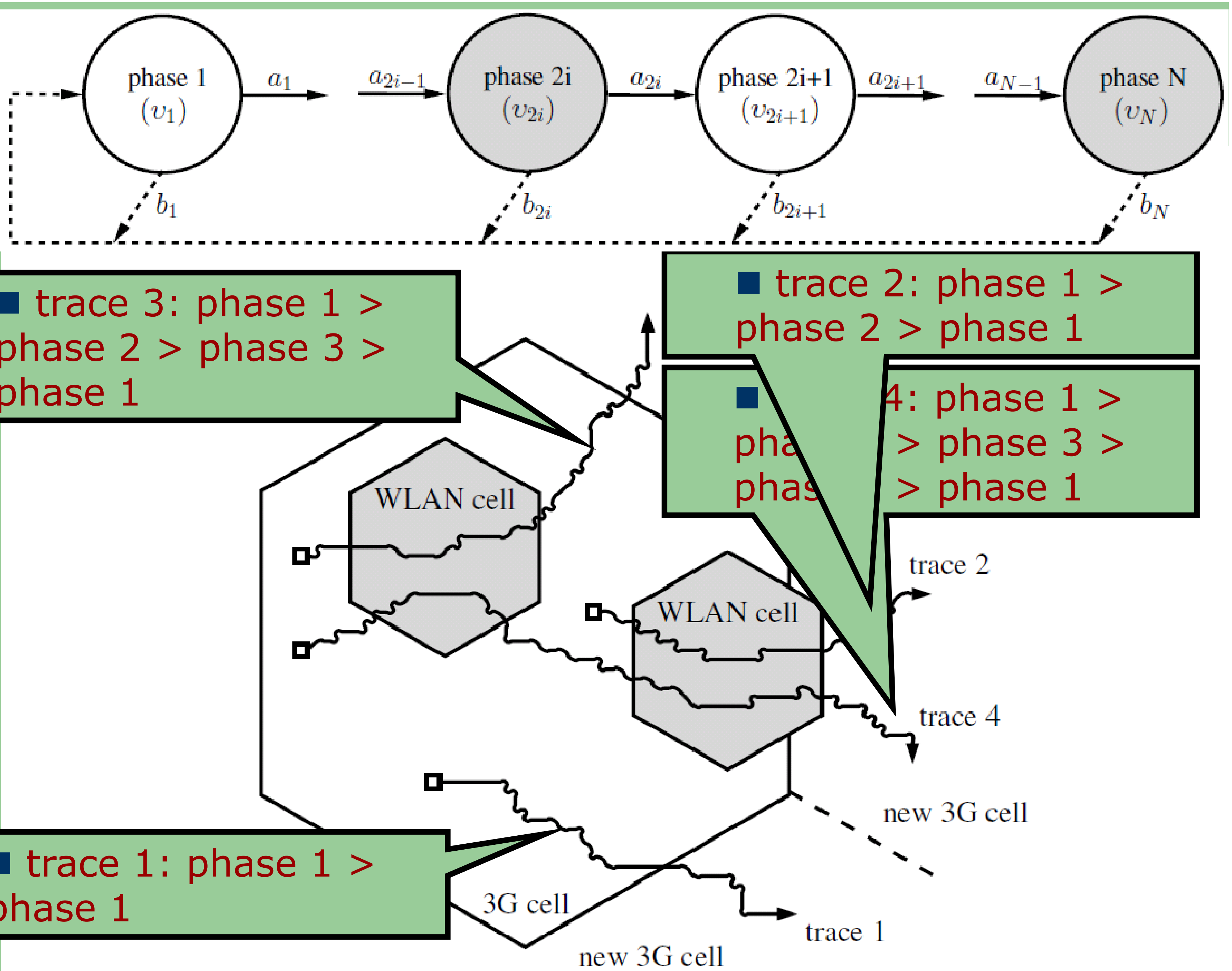
■ transitions back to phase 1: movements out of a compound cell and entering another one

■ odd phases: 3G only

■ transitions between neighbouring phases: movements between different RAT areas



- Two assumptions are made:
  - WLAN cells do not overlap with each other;
    - HHO between WLAN cells is not considered
  - WLAN cells that overlap with adjacent cellular cells belong to all the cellular cells;
    - the start point of the track of the mobile node in a 3G-WLAN compound cell is always the 3G area



- trace 3: phase 1 > phase 2 > phase 3 > phase 1
- trace 2: phase 1 > phase 2 > phase 1
- 4: phase 1 > pha > phase 3 > phas > phase 1
- trace 1: phase 1 > phase 1

PEPA models for NSSs (general description)

- In the PEPA model for NSSs, a mobile node
  - can generate different types of sessions, and these sessions are submitted to different networks according to NSSs (parameters P_C and P_W are used in the definitions of PEPA models);
  - can perform different types of handovers according to the NSSs;
  - is aware of network blocking for both new and handover sessions in 3G and WLAN networks (parameters P_B^C and P_B^W are used in the definitions of PEPA models);
  - is aware of the different data rates that are provided by different RATs; (NRT sessions (e.g. file downloading) usually need less time using WLAN RAT than using 3G RAT)

…erfor…

…tate of

■ *A*, the network the mobile node is connected to

■ *B*, the type of the session the mobile node is engaged in

$$s_k^{A,B}$$

■ *k*, the mobile node's phase of its mobility model

…sures are investigated:

- ☐ handover rate;
- ☐ network blocking probability;

Av

- the percentage of time the mobile node spends using different RATs for different types of sessions

- time percentages:

$$T_{C,NRT} = \sum_{i=1}^{N} \pi(s_i^{C,NRT}), \qquad T_{C,RT} = \sum_{i=1}^{N} \pi(s_i^{C,RT}),$$

$$T_{W,NRT} = \sum_{i=1}^{N/2} \pi(s_{2i}^{W,NRT}), \qquad T_{W,RT} = \sum_{i=1}^{N/2} \pi(s_{2i}^{W,RT}),$$

- then, calculate the total engaged time of the mobile node:

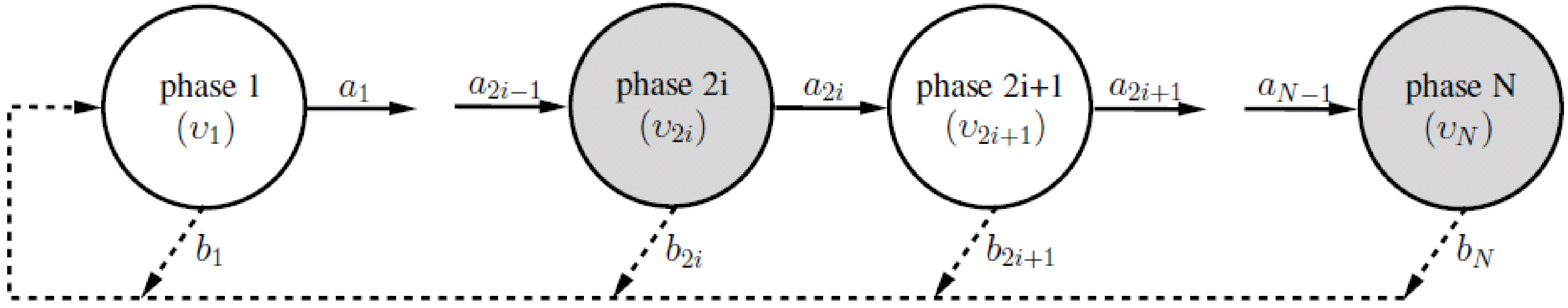
$$T_{Engaged} = T_{C,NRT} + T_{C,RT} + T_{W,NRT} + T_{W,RT}$$

Average throughput

- then, the average throughput is defined as a weighted sum:

$$THP = D^C_{NRT} * \frac{T_{C,NRT}}{T_{Engaged}} + D^C_{RT} * \frac{T_{C,RT}}{T_{Engaged}} + D^W_{NRT} * \frac{T_{W,NRT}}{T_{Engaged}} + D^W_{RT} * \frac{T_{W,RT}}{T_{Engaged}},$$

- the data rates that can be achieved using different RATs for different sessions



$$r_{C-C}^{inter} = \sum_{i=1}^{N/2} \left(b_{2i-1} * v_{2i-1} * \pi(s_{2i-1}^{C}) + b_{2i} * v_{2i} * \pi(s_{2i}^{C}) \right)$$

$$r_{W-C}^{inter} = \sum_{i=1}^{N/2} b_{2i} * v_{2i} * \pi(s_{2i}^{W}),$$

$$r_{C-W}^{intra} = \sum_{i=1}^{N/2} P_W * a_{2i-1} * v_{2i-1} * \pi(s_{2i-1}^{C}),$$

$$r_{W-C}^{intra} = \sum_{i=1}^{N/2} a_{2i} * v_{2i} * \pi(s_{2i}^{W}),$$

Network blocking probability

- Like network selection probabilities, these network blocking probabilities can be used as input parameters.

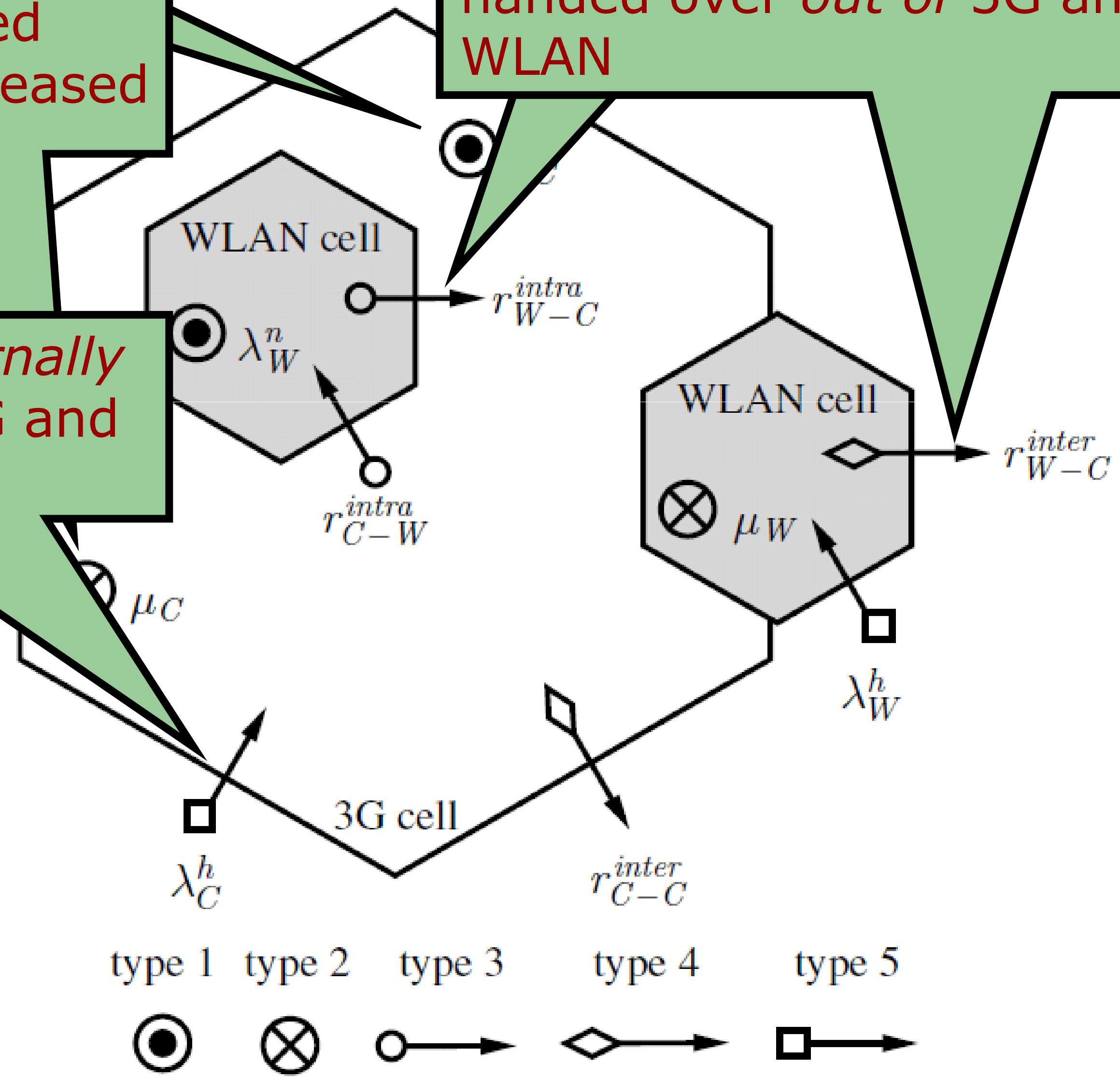
- In this work, they are derived from a 2D-CTMC that models the resource consumption of a 3G-WLAN compound cell.

  - the state of the 2D-CTMC is denoted by two integers (c,w), where c and w represent the numbers of engaged users in 3G and WLAN networks respectively;

probabi…

…of events t…

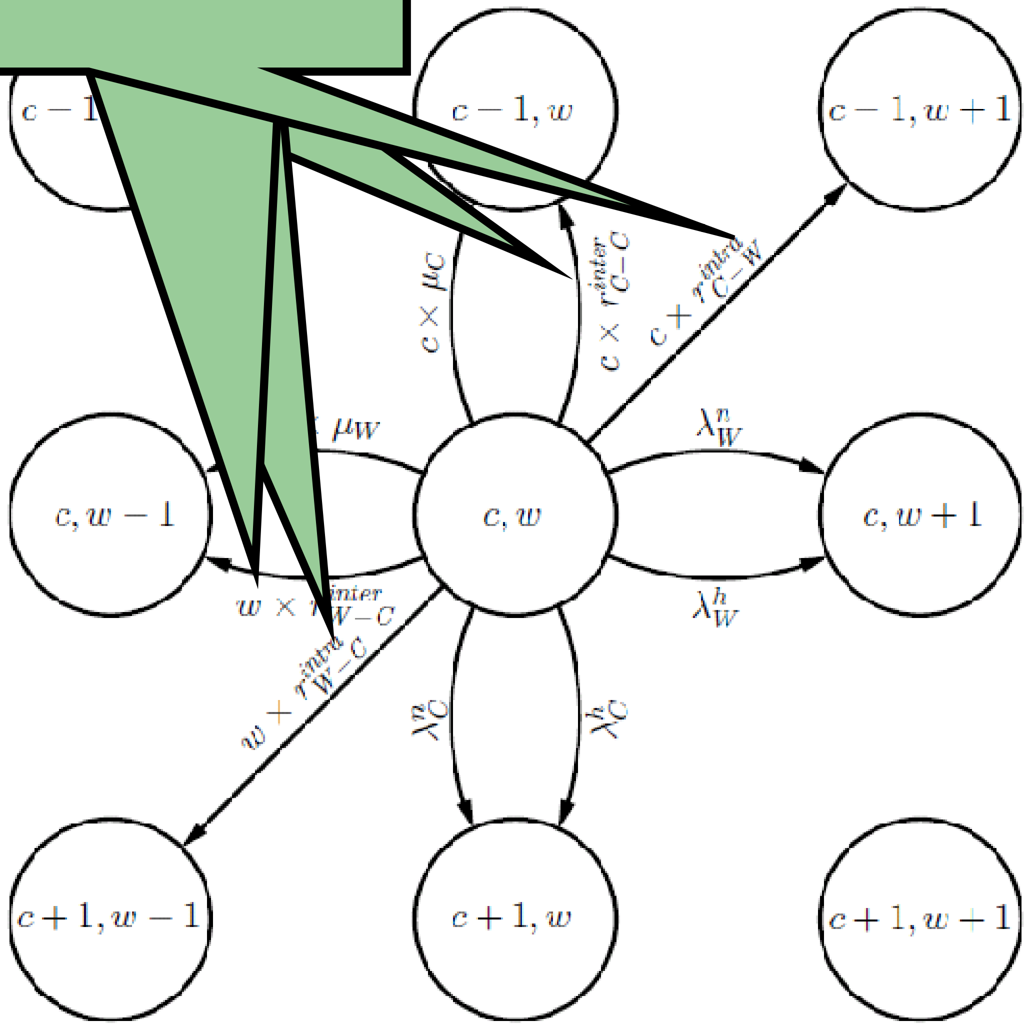
- new session requests are generated in 3G and WLAN networks
- sessions are finished and resources are released
- sessions are *internally* handed over *between* 3G
- sessions are *externally* handed over *out of* 3G and WLAN
- sessions are *externally* handed over *into* 3G and WLAN



Network blocking probability

■ note that the definition of the 2D-CTMC uses handover rates as parameters

...e outward transitions of a non-... the 2D-CTMC is



Network blocking probability

- The blocking probabilities of 3G and WLAN networks are then calculated as:

$$P_B^C = \sum_{\substack{c=N_C \\ 0 \leqslant w \leqslant N_W}} p(c,w), \quad P_B^W = \sum_{\substack{w=N_W \\ 0 \leqslant c \leqslant N_C}} p(c,w),$$

An implicit problem

- As presented above, the derivation of network blocking probabilities from the 2D-CTMC model requires handover rates as input parameters.

- On the other hand, to derive handover rates from the PEPA

- handover rat
- injected int CTMC model
- calculate network blocking probabilities
- network bloc probabilities
- injected int models
- calculate handover rates

$$F_{CTMC}(\boldsymbol{R}_H): \quad \boldsymbol{R}_H \xrightarrow{f_{CTMC}} \boldsymbol{p}(c,w) \longrightarrow \boldsymbol{P}_B,$$

$$F_{PEPA}(\boldsymbol{P}_B): \quad \boldsymbol{P}_B \xrightarrow{f_{PEPA}} \boldsymbol{\pi}(s_k^{A,B}) \longrightarrow \boldsymbol{R}_H,$$

$$\boldsymbol{R}_H = \left[r_{C-W}^{intra}, r_{W-C}^{intra}, r_{C-C}^{inter}, r_{W-C}^{inter}\right] \quad \boldsymbol{P}_B = \left[P_B^C, P_B^W\right]$$

Convergence speed

- The convergence speed of the above iterative method is dependent on the parameter settings but very fast.
  - four types of NSSs have been investigated with 10 increasing session durations --- as the table shows in each case only a low number of iterations was needed.

Model	Numbers of iterations
Random	[2, 2, 3, 4, 5, 7, 9, 11, 11, 13]
RRSS	[2, 2, 3, 4, 5, 7, 8, 11, 12, 13]
WLAN-first	[2, 2, 3, 4, 5, 6, 8, 10, 12, 13]
Service-based	[2, 2, 3, 4, 5, 6, 8, 10, 12, 13]

  - moreover, the results of the method are NOT dependent on the initial values of network blocking probabilities

Evaluation Results

Four types of NSSs

- Random:
  - the mobile node selects 3G and WLAN with equal probabilities, i.e., 0.5;
- Relative received signal strength (RRSS):
  - the mobile node selects the network with the strongest signal strength;
- WLAN-first:
  - the mobile node always choose WLAN when it is available, because of its high bandwidth, small delay and cheap cost;
- Service-based:
  - the mobile node selects 3G for RT sessions (for less handovers) and WLAN for NRT sessions (for high data rate);

Parameter settings

- Network selection probabilities of different NSSs are:

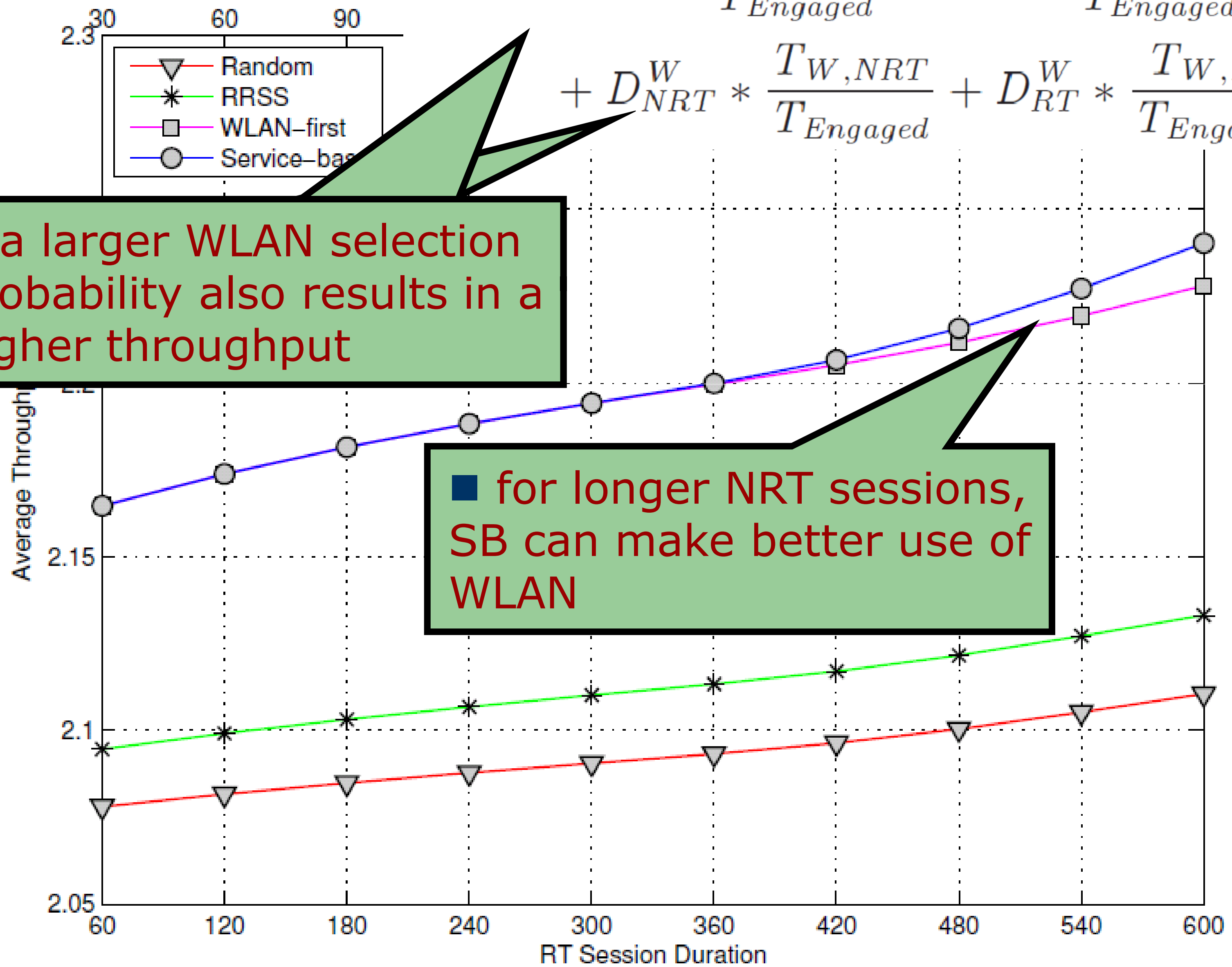
Network selection probabilities		
Random	$P_C = 0.5$	$P_W = 0.5$
RRSS	$P_C = 0.4$	$P_W = 0.6$ [10]
WLAN-first	$P_C = 0$	$P_W = 1$
Service-based	$P_C = 1$ (for RT session)	
	$P_W = 1$ (for NRT session)	

Controlled parameters

- Effect of two mobility patterns
  - mobility pattern 1 ($t_{3G\text{-}WLAN}$=474, P_{NRT}=P_{RT}=0.5)
  - mobility pattern 2 ($t_{3G\text{-}WLAN}$=1200, P_{NRT}=P_{RT}=0.5)

mobility pattern 1 ($t_{3G\text{-}WLAN}$=474, P_{NRT}=P_{RT}=0.5)

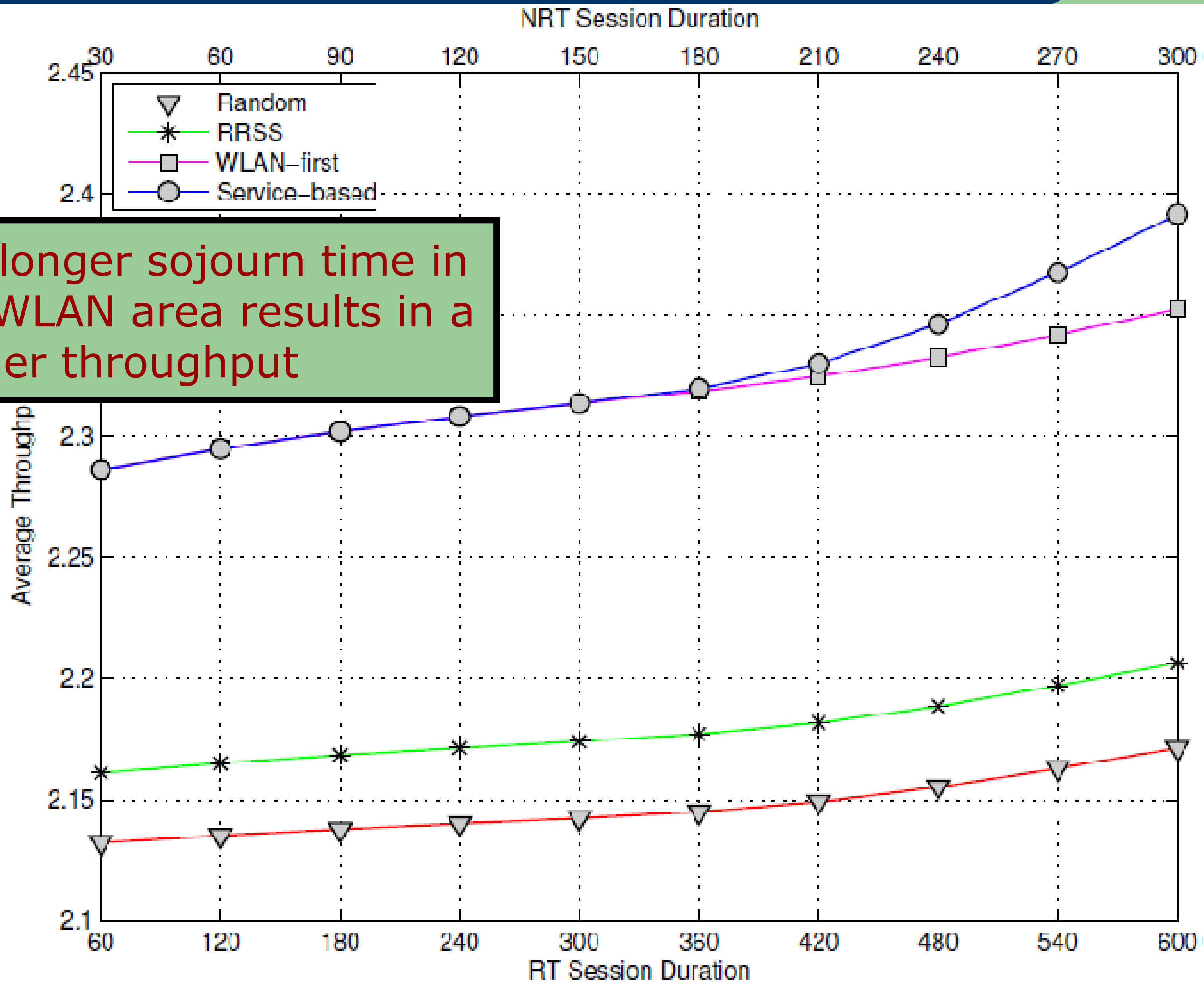
$$THP = D^{C}_{NRT} * \frac{T_{C,NRT}}{T_{Engaged}} + D^{C}_{RT} * \frac{T_{C,RT}}{T_{Engaged}} + D^{W}_{NRT} * \frac{T_{W,NRT}}{T_{Engaged}} + D^{W}_{RT} * \frac{T_{W,RT}}{T_{Engaged}},$$



- a larger WLAN selection probability also results in a higher throughput

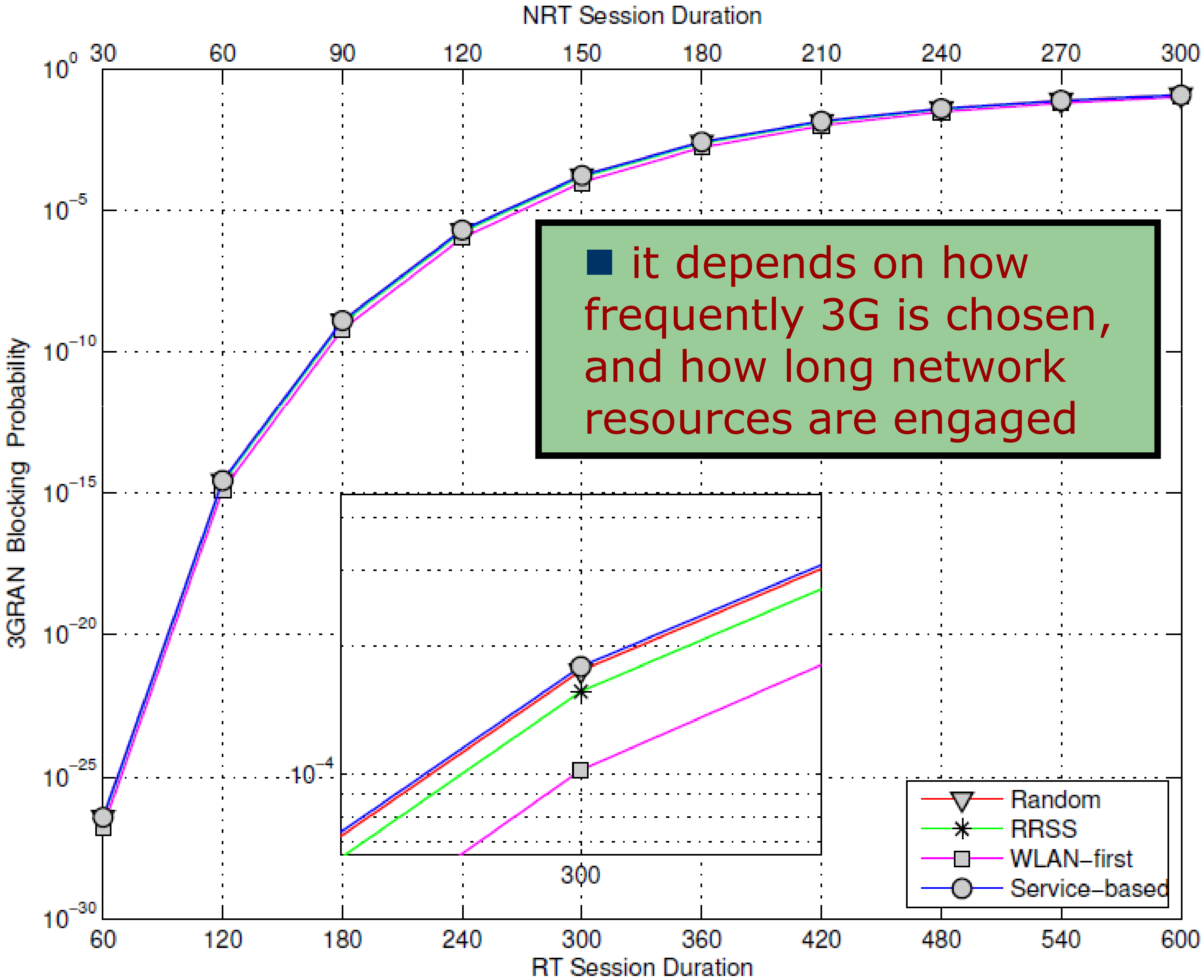
- for longer NRT sessions, SB can make better use of WLAN

mobility pattern 2 ($t_{3G\text{-}WLAN}$=1200, P_{NRT}=P_{RT}=0.5)

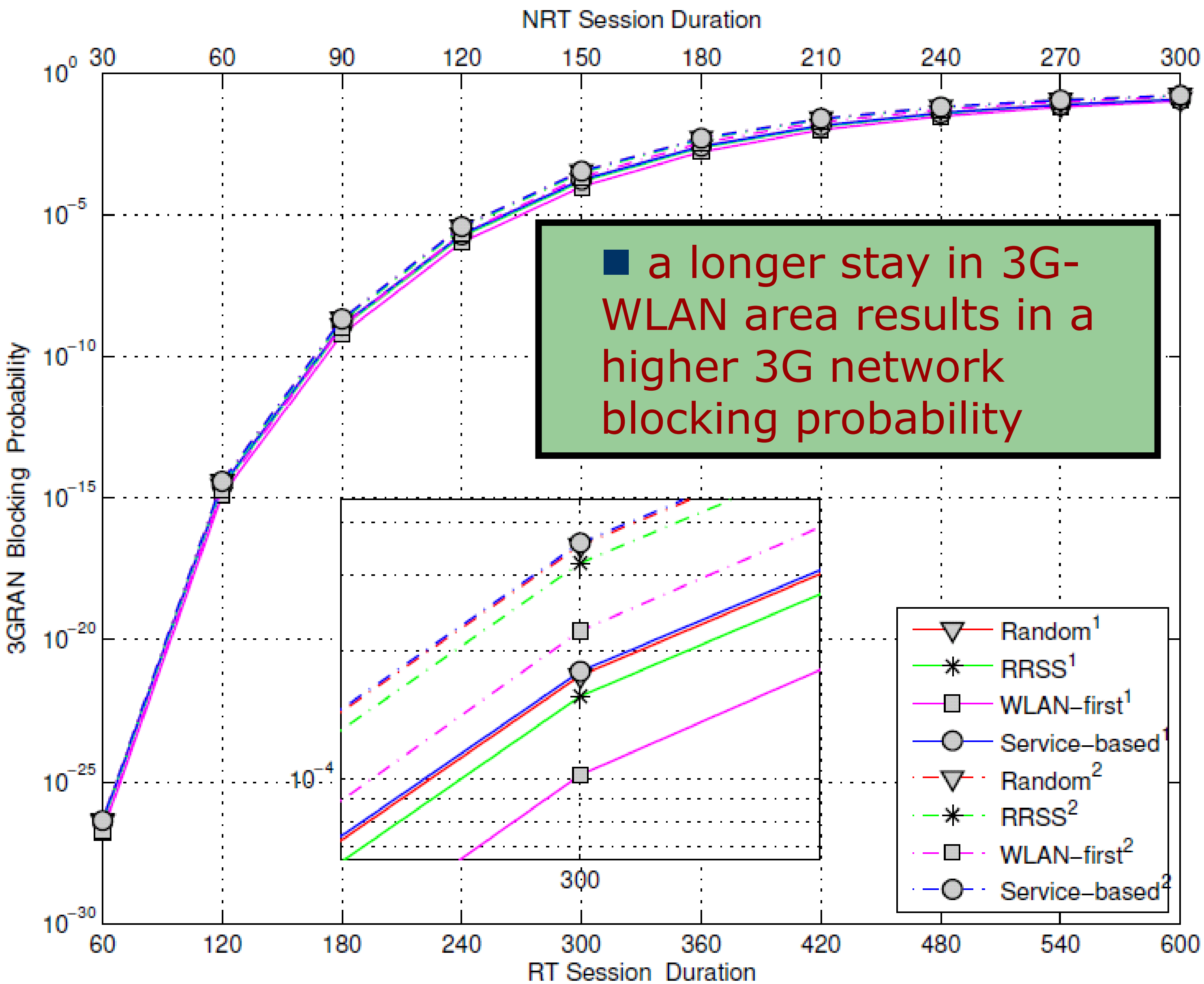


- a longer sojourn time in 3G-WLAN area results in a higher throughput

mobility pattern 1 ($t_{3G\text{-}WLAN}$=474, P_{NRT}=P_{RT}=0.5)



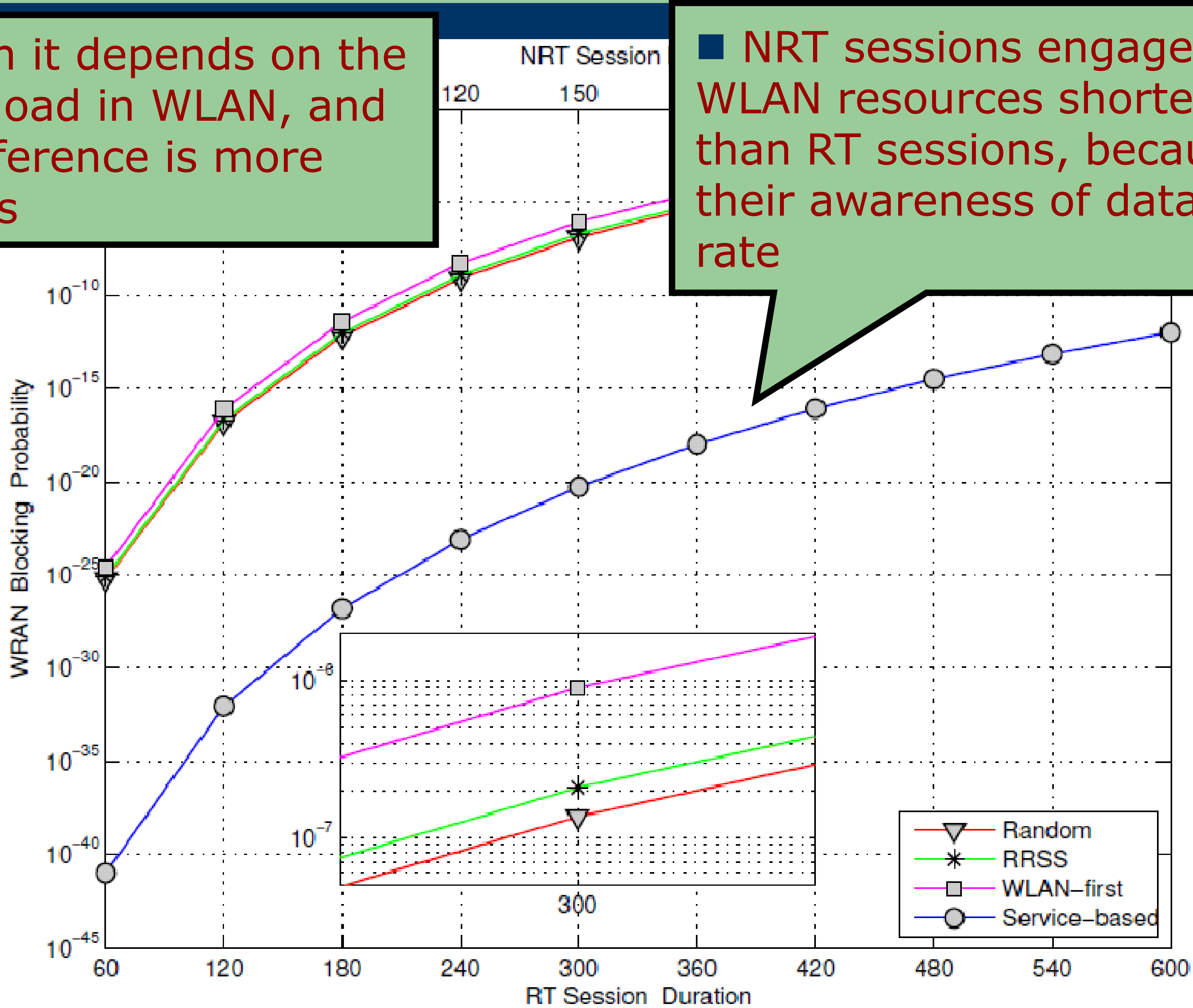
- it depends on how frequently 3G is chosen, and how long network resources are engaged mobility pattern 1 ($t_{3G\text{-}WLAN}$=474, P_{NRT}=P_{RT}=0.5) and mobility pattern 2 ($t_{3G\text{-}WLAN}$=1200, P_{NRT}=P_{RT}=0.5)



- a longer stay in 3G-WLAN area results in a higher 3G network blocking probability mobility pattern 1 ($t_{3G\text{-}WLAN}$=474, $P_{NRT}=P_{RT}$=0.5)

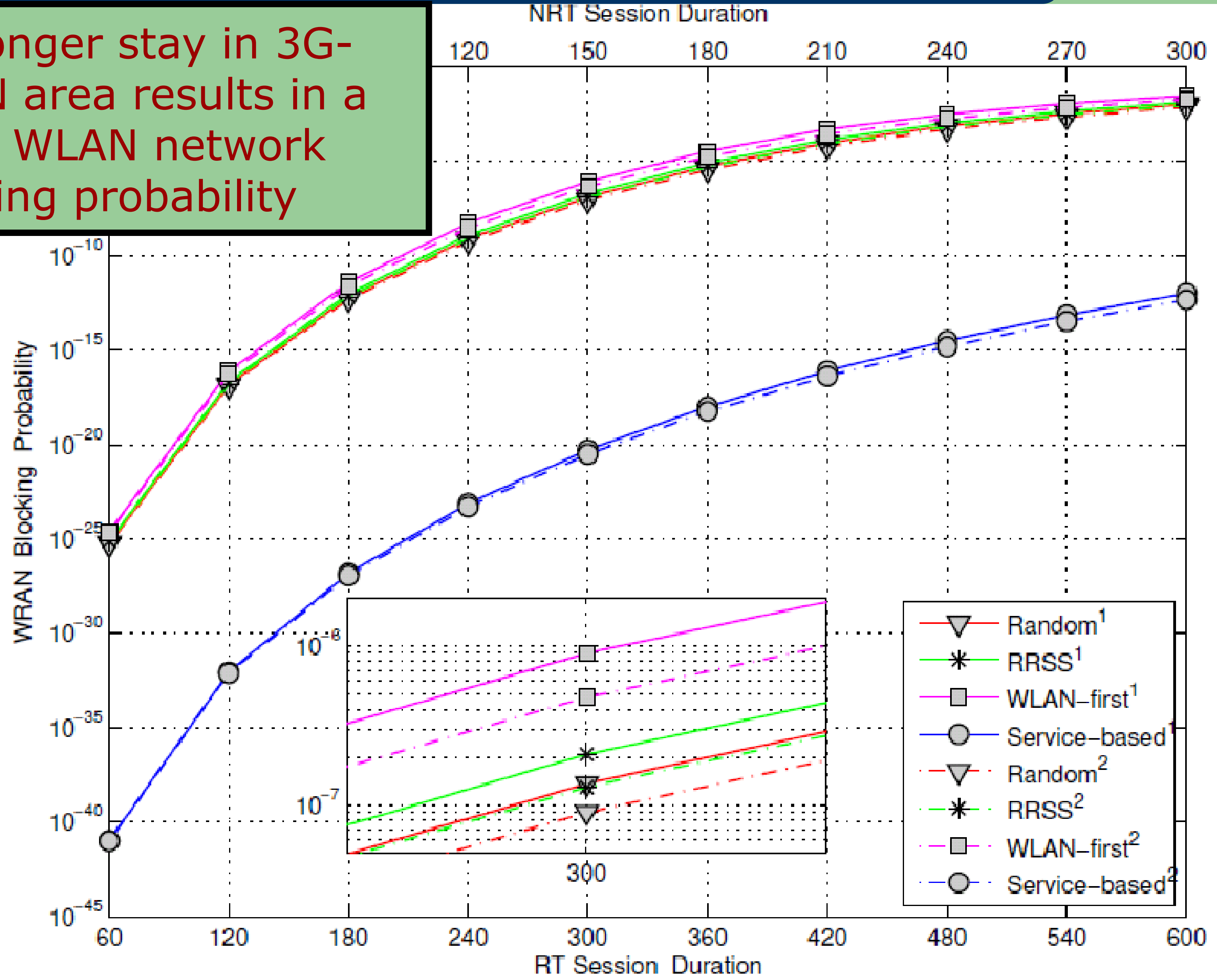
- again it depends on the traffic load in WLAN, and the difference is more obvious

- NRT sessions engage WLAN resources shorter than RT sessions, because their awareness of data rate

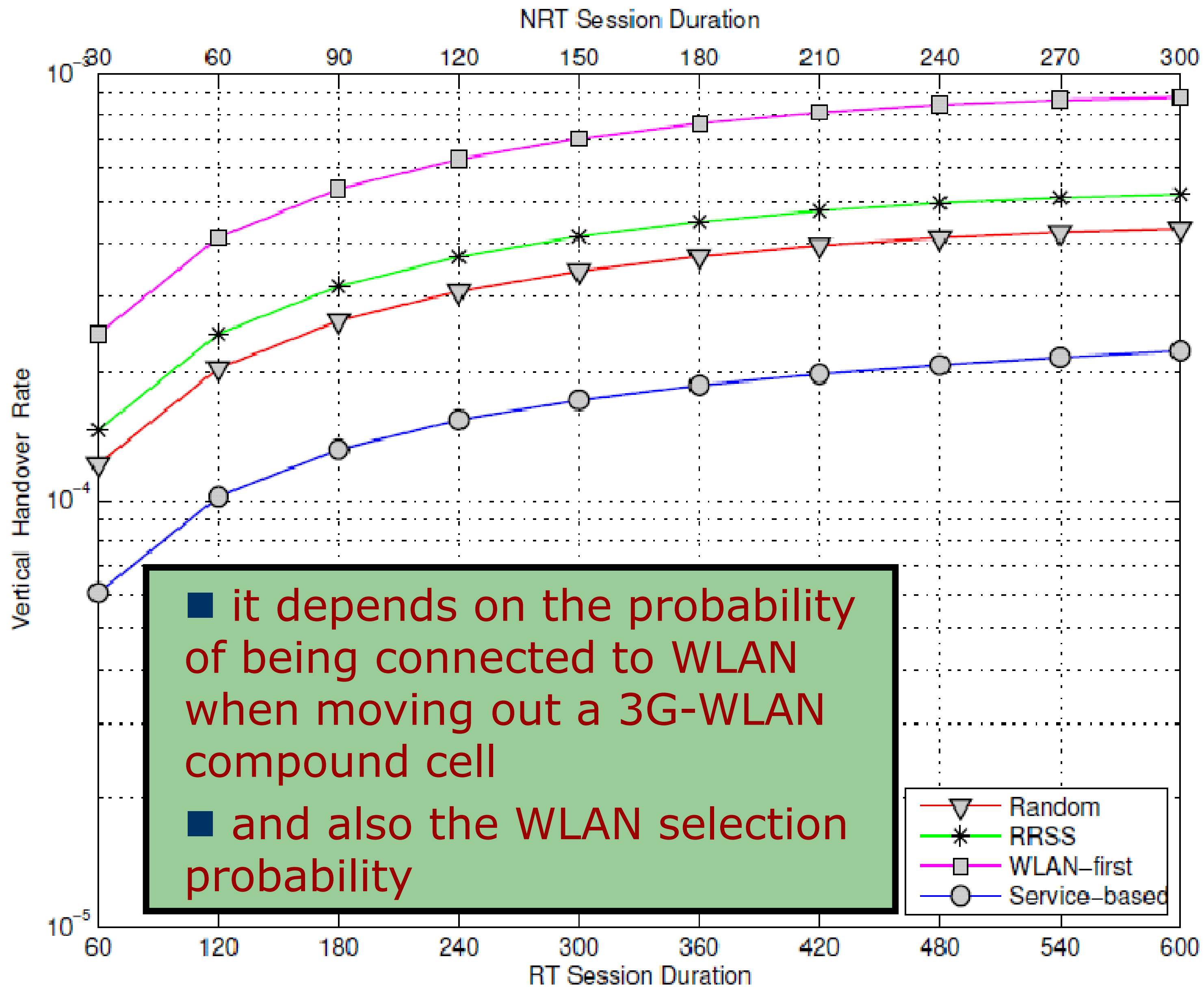


mobility pattern 1 ($t_{3G\text{-}WLAN}$=474, P_{NRT}=P_{RT}=0.5) and mobility pattern 2 ($t_{3G\text{-}WLAN}$=1200, P_{NRT}=P_{RT}=0.5)

- a longer stay in 3G-WLAN area results in a lower WLAN network blocking probability

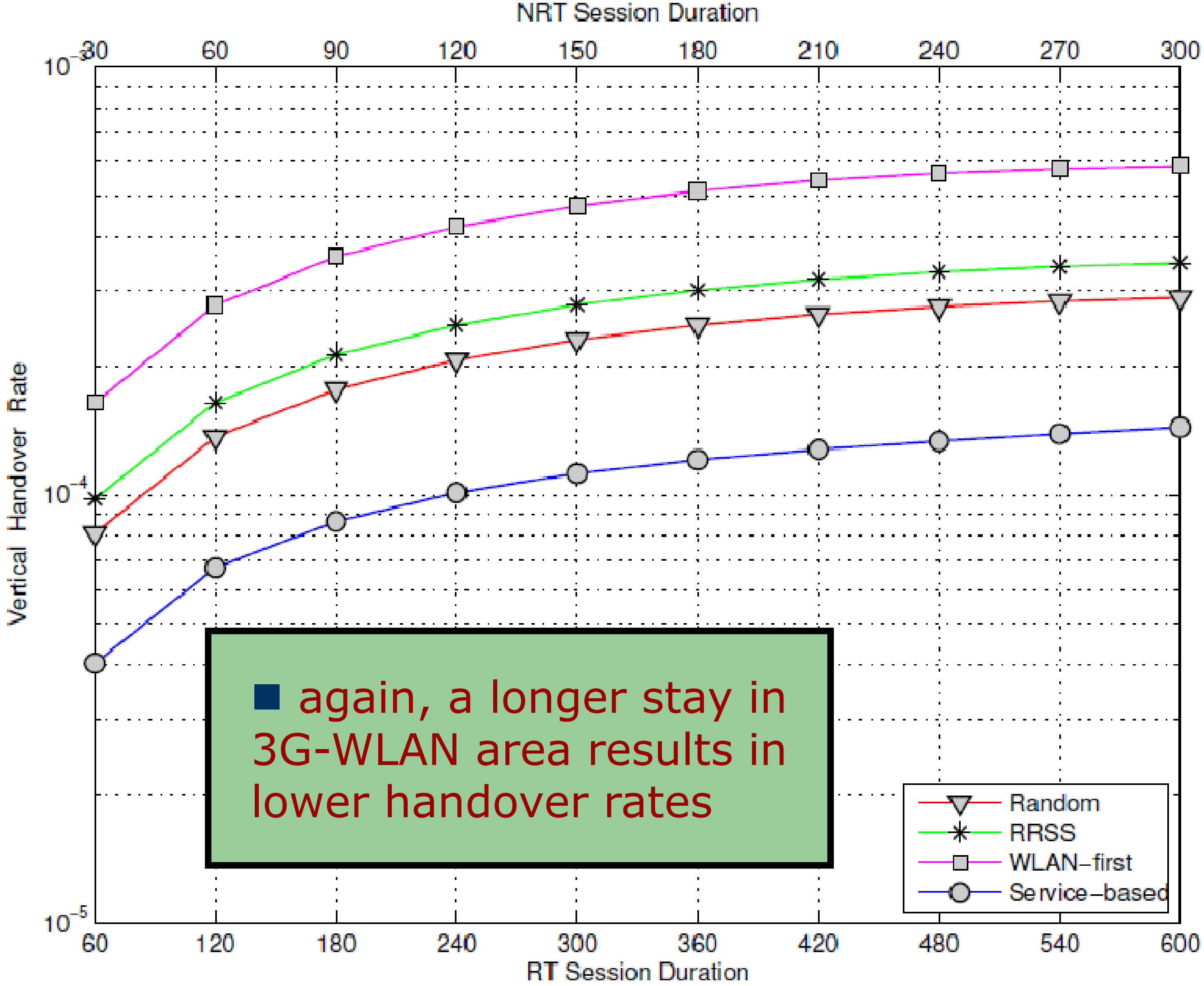


mobility pattern 1 ($t_{3G\text{-}WLAN}=474$, $P_{NRT}=P_{RT}=0.5$)



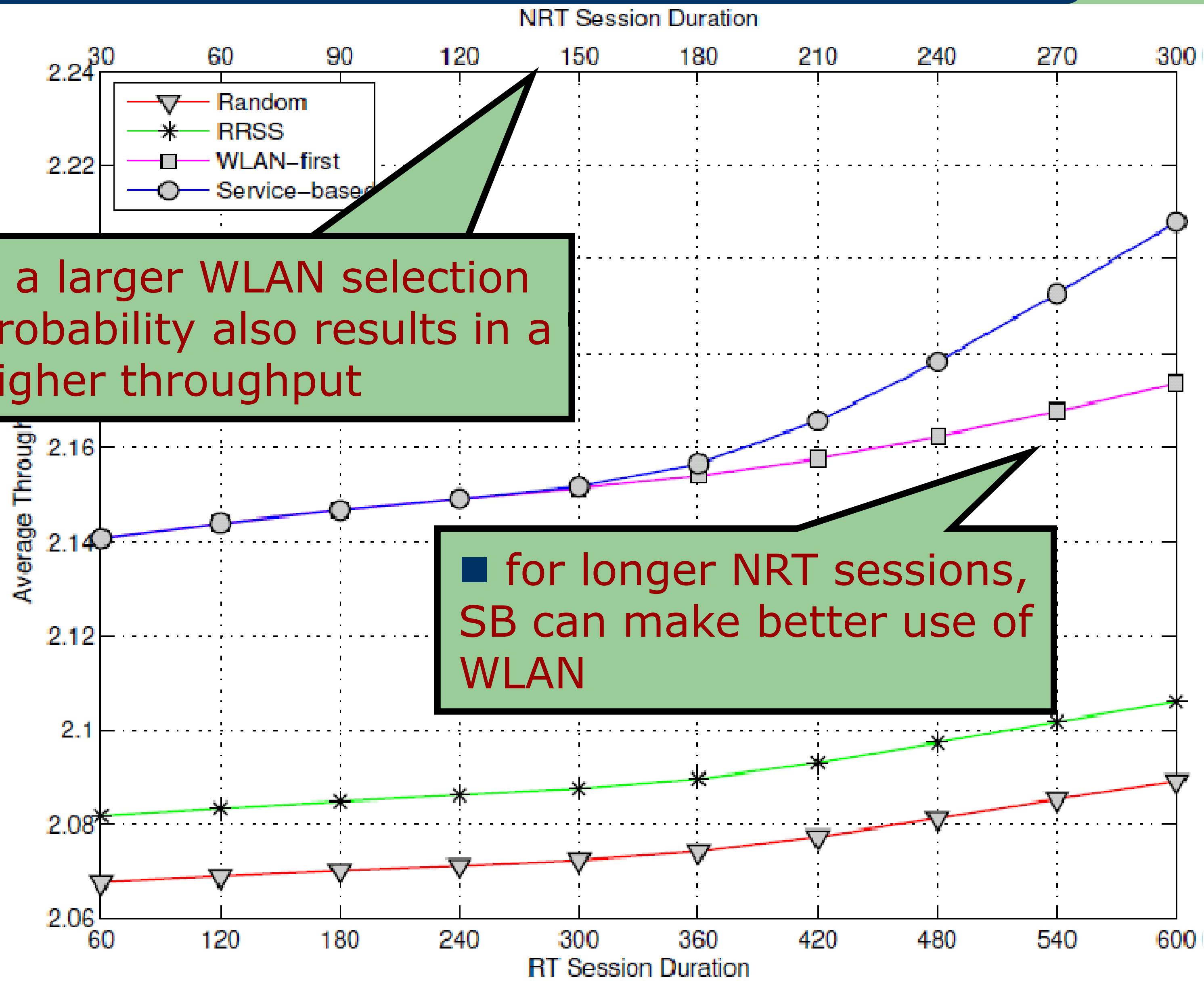
- it depends on the probability of being connected to WLAN when moving out a 3G-WLAN compound cell
- and also the WLAN selection probability

mobility pattern 2 ($t_{3G\text{-}WLAN}$=1200, P_{NRT}=P_{RT}=0.5)



- again, a longer stay in 3G-WLAN area results in lower handover rates

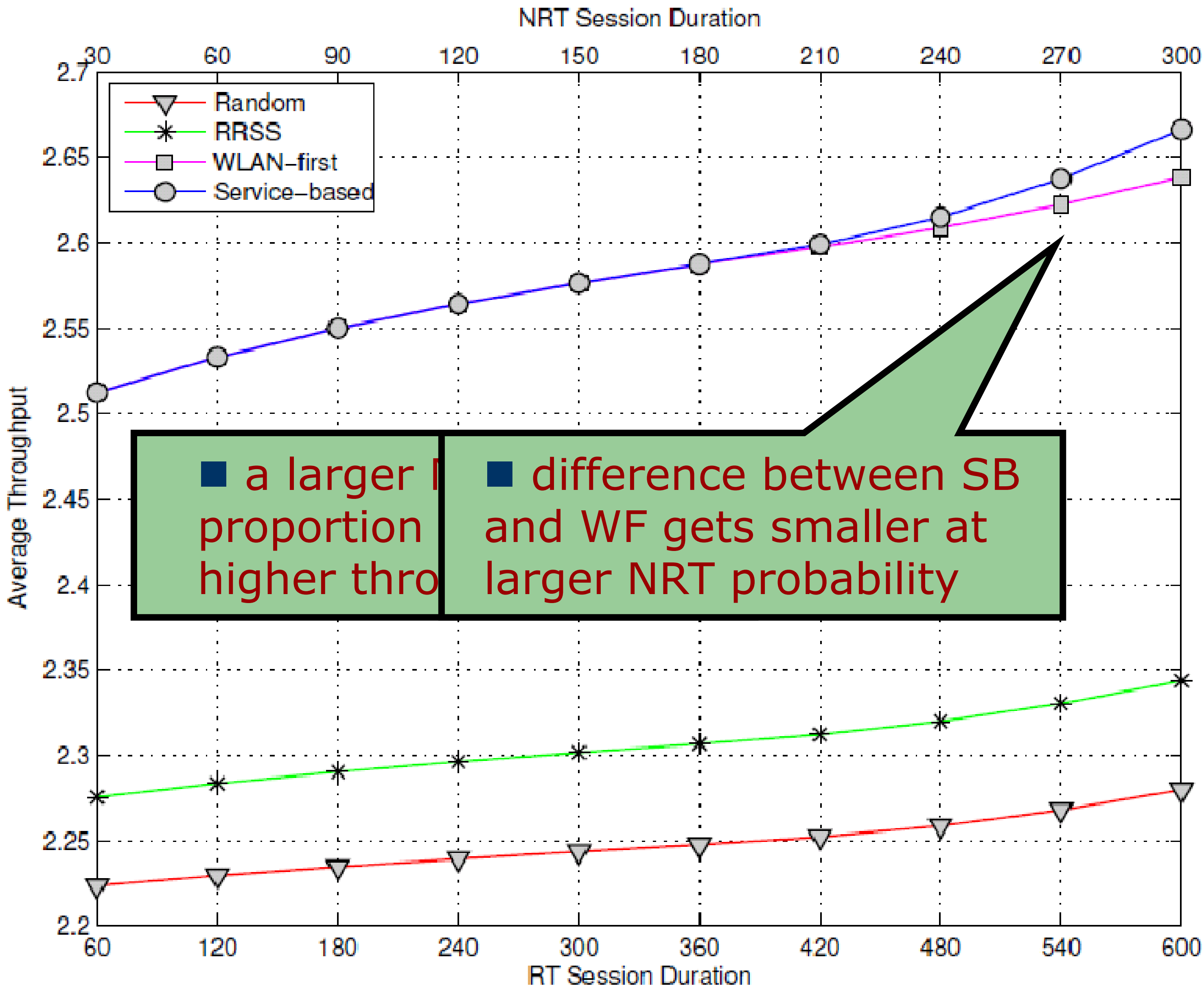
traffic pattern 1 ($t_{3G\text{-}WLAN}$=1200, P_{NRT}=0.3 P_{RT}=0.7)



- a larger WLAN selection probability also results in a higher throughput

- for longer NRT sessions, SB can make better use of WLAN

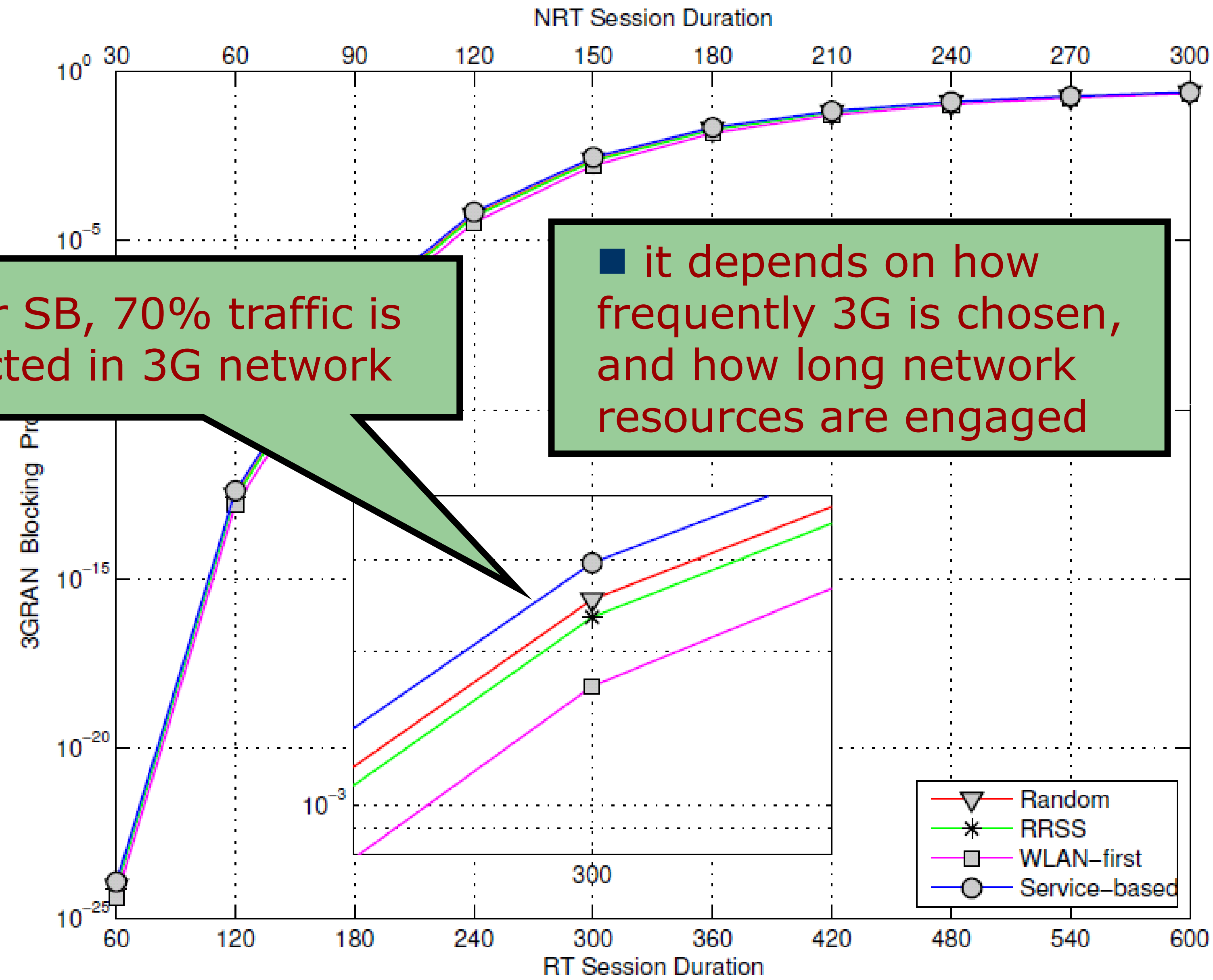
traffic pattern 2 ($t_{3G\text{-}WLAN}$=1200, P_{NRT}=0.7 P_{RT}=0.3)



- a larger proportion higher thro

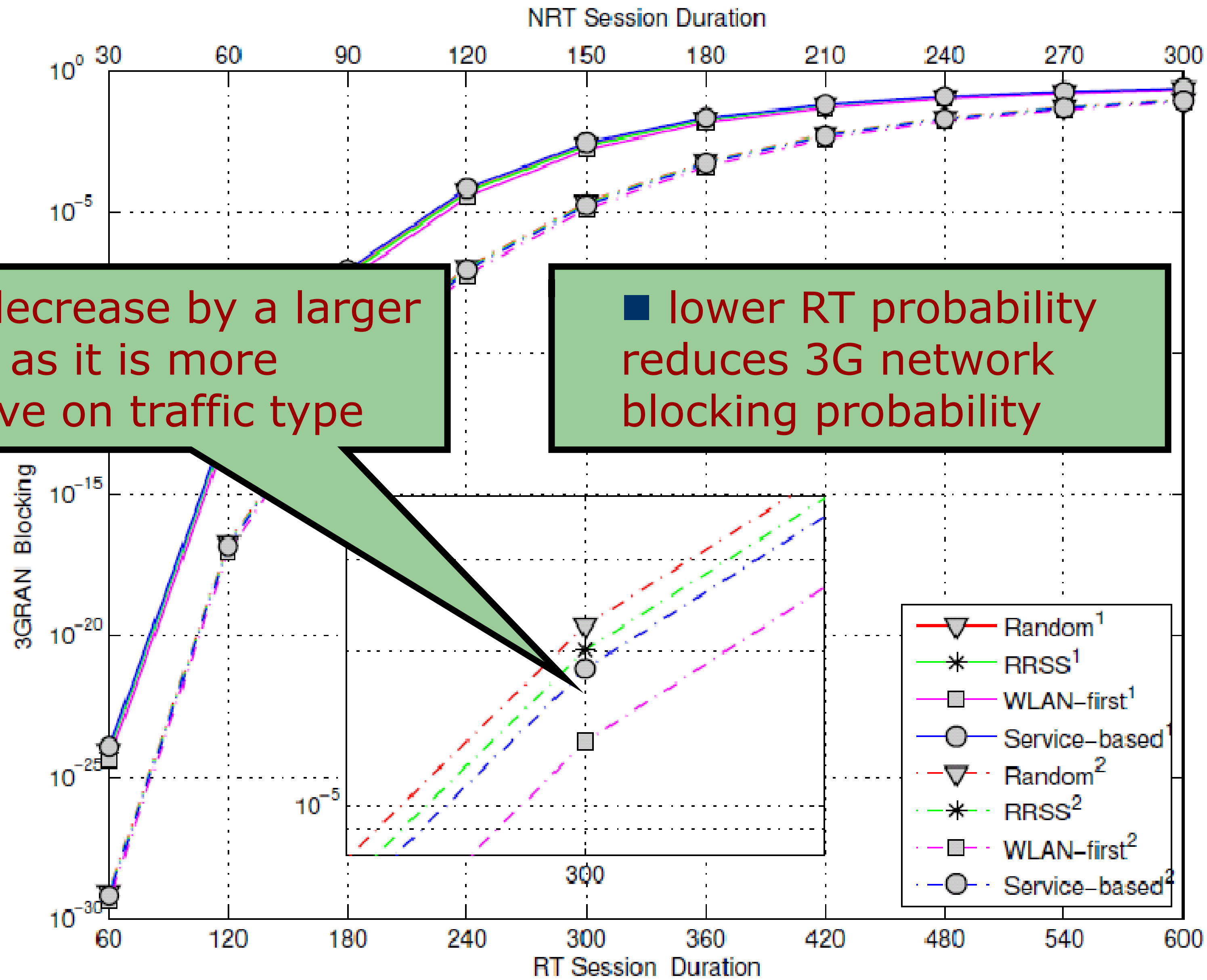
- difference between SB and WF gets smaller at larger NRT probability

traffic pattern 1 ($t_{3G\text{-}WLAN}=1200$, $P_{NRT}=0.3$ $P_{RT}=0.7$)



- for SB, 70% traffic is injected in 3G network

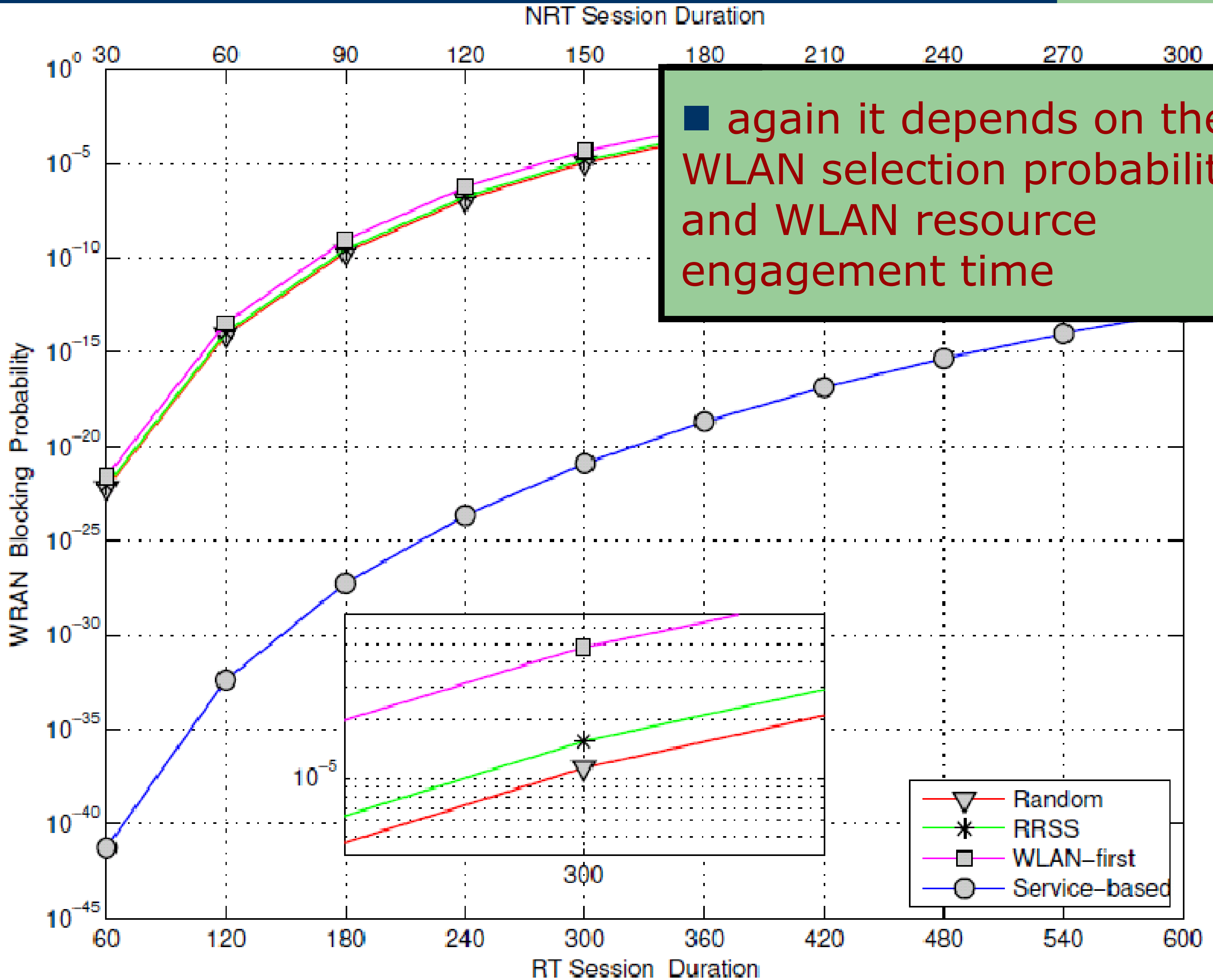
- it depends on how frequently 3G is chosen, and how long network resources are engaged traffic pattern 1 ($t_{3G\text{-}WLAN}$=1200, P_{NRT}=0.3 P_{RT}=0.7) and traffic pattern 2 ($t_{3G\text{-}WLAN}$=1200, P_{NRT}=0.7 P_{RT}=0.3)



- SB decrease by a larger extent as it is more sensitive on traffic type

- lower RT probability reduces 3G network blocking probability

traffic pattern 1 ($t_{3G\text{-}WLAN}$=1200, P_{NRT}=0.3 P_{RT}=0.7)

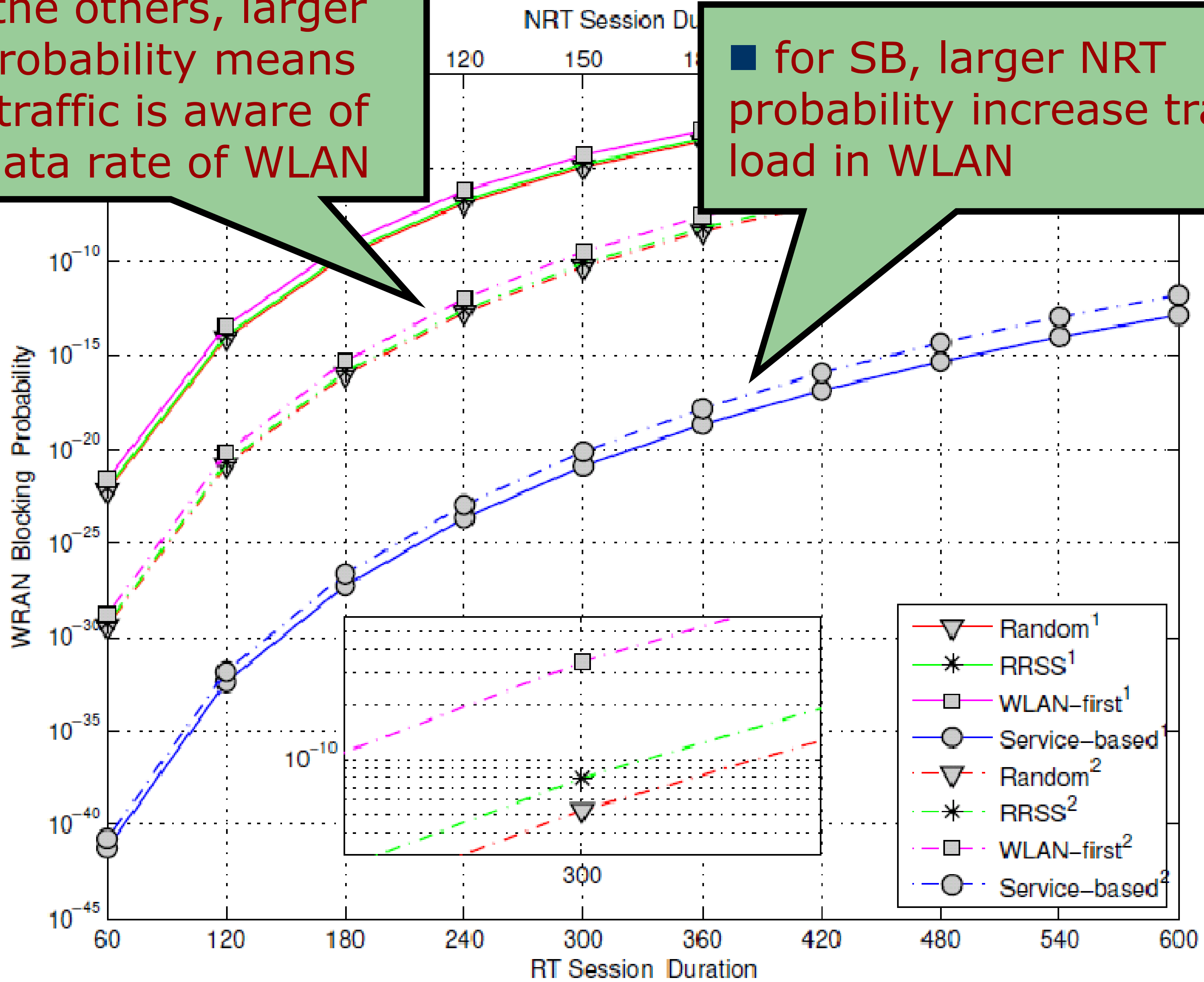


- again it depends on the WLAN selection probability and WLAN resource engagement time

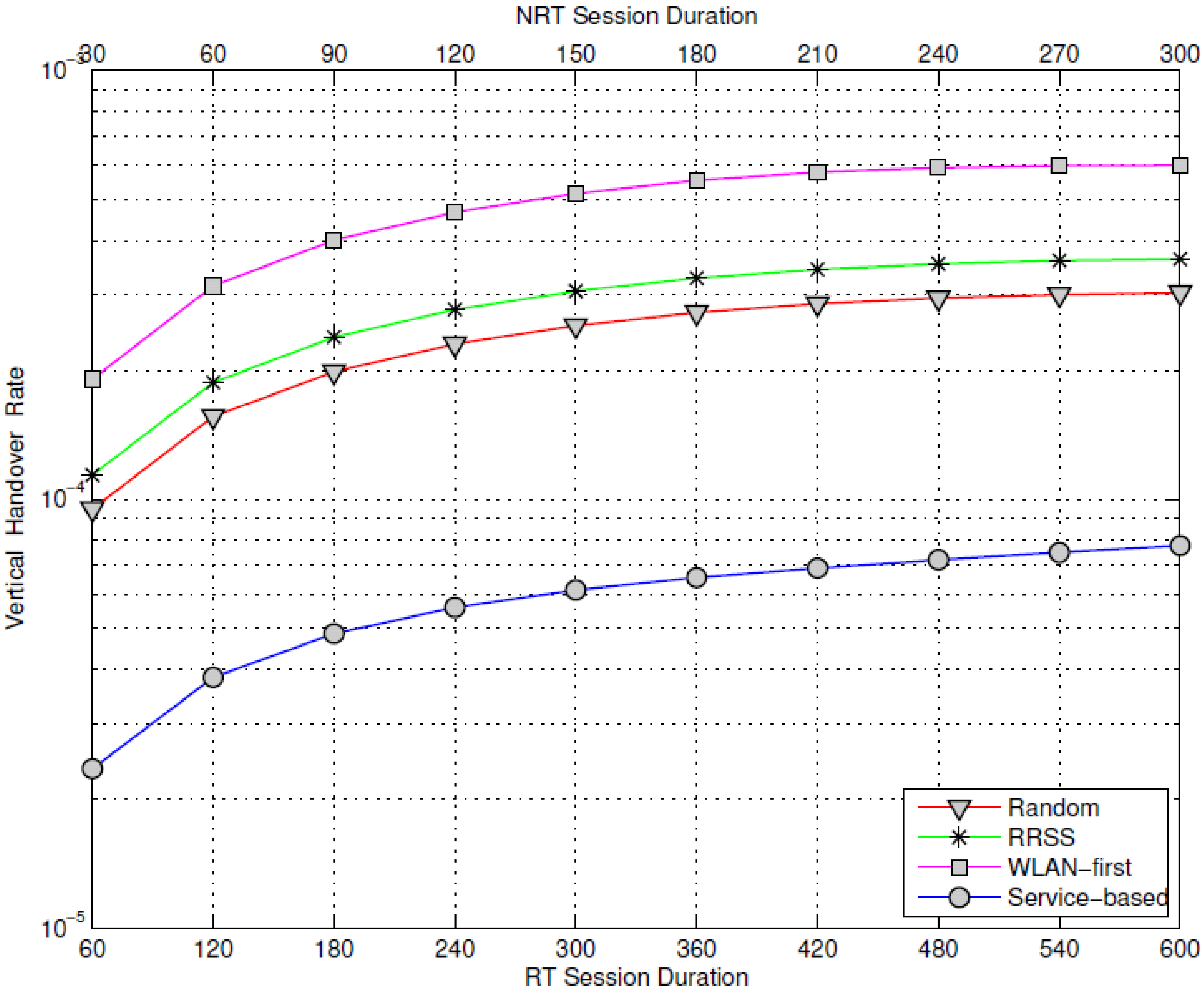
traffic pattern 1 ($t_{3G\text{-}WLAN}$=1200, P_{NRT}=0.3 P_{RT}=0.7) and
traffic pattern 2 ($t_{3G\text{-}WLAN}$=1200, P_{NRT}=0.7 P_{RT}=0.3)

- for the others, larger NRT probability means more traffic is aware of high data rate of WLAN

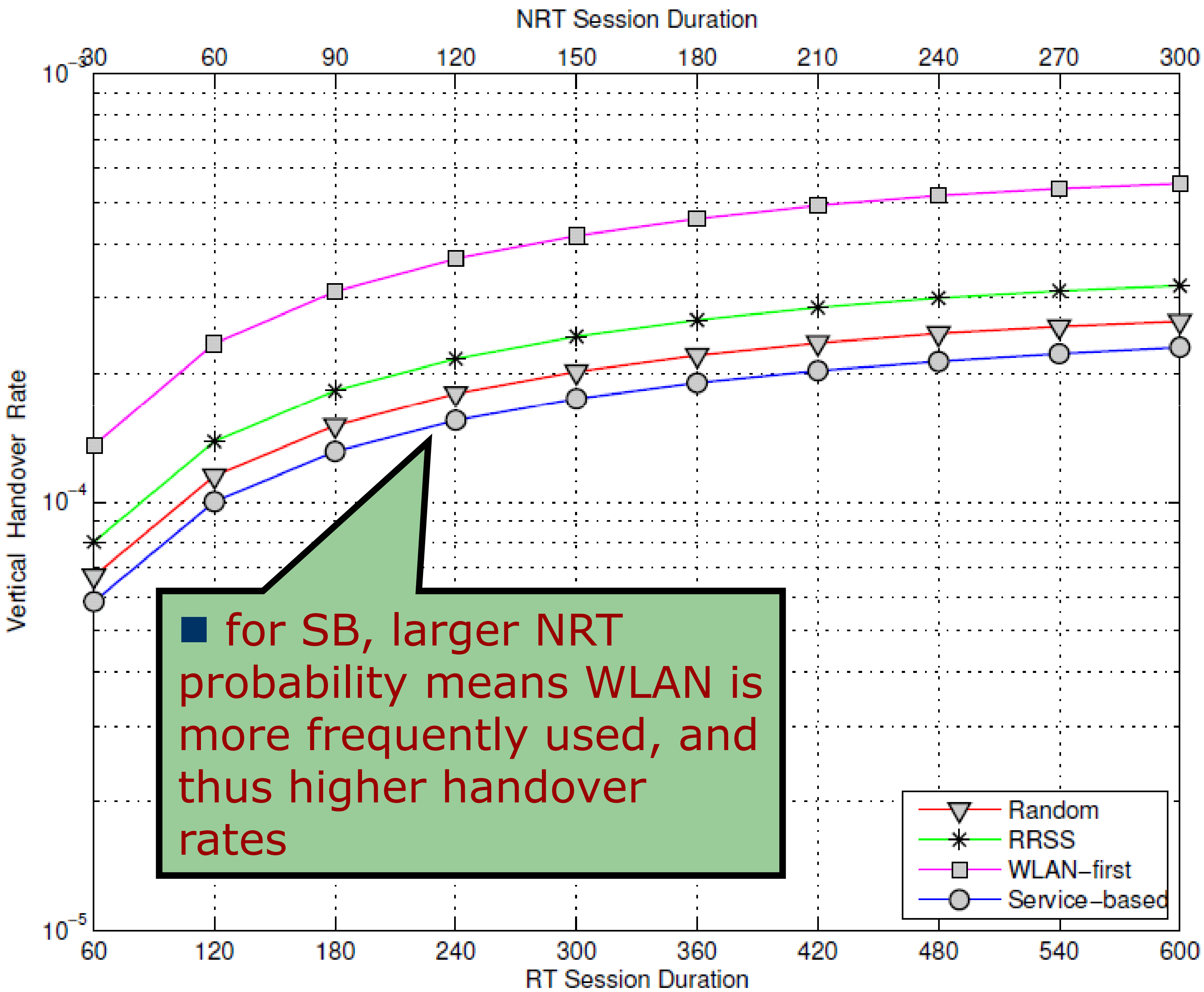
- for SB, larger NRT probability increase traffic load in WLAN



traffic pattern 1 ($t_{3G\text{-}WLAN}$=1200, P_{NRT}=0.3 P_{RT}=0.7)



traffic pattern 2 ($t_{3G\text{-}WLAN}$=1200, P_{NRT}=0.7 P_{RT}=0.3)



- for SB, larger NRT probability means WLAN is more frequently used, and thus higher handover rates

Conclusions

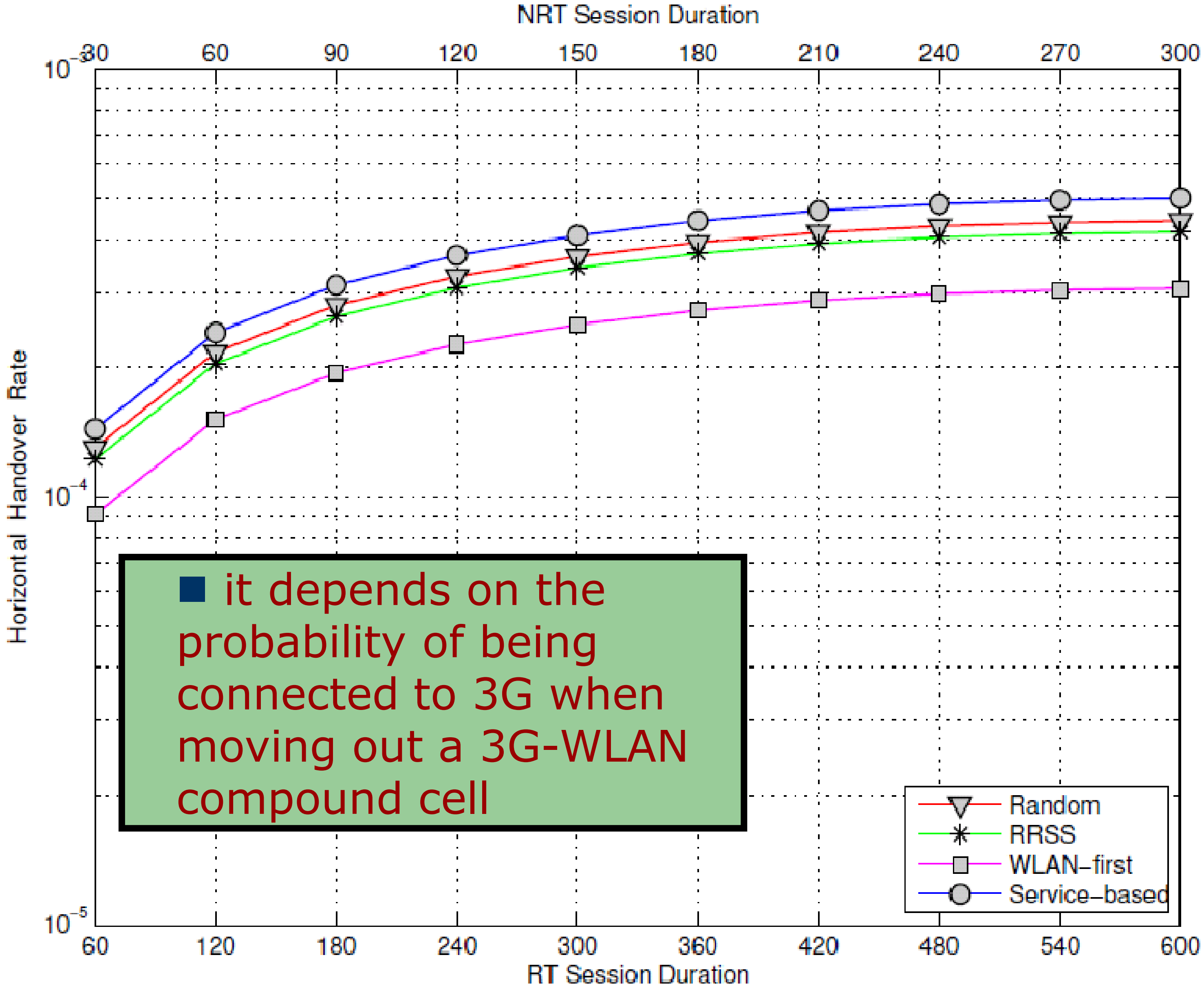
In conclusion

- For deterministic strategies (service-based and WLAN-first):
  - easy to implement;
  - user knows which network is connected to;
  - their performance in terms of the investigated measures are usually the boundaries of the studies strategies;

- For non-deterministic strategies (RRSS and random):
  - not easy to implement
  - users experience uncertainty during handover;
  - they produce more balanced performance on the investigated measures;

Thank You!

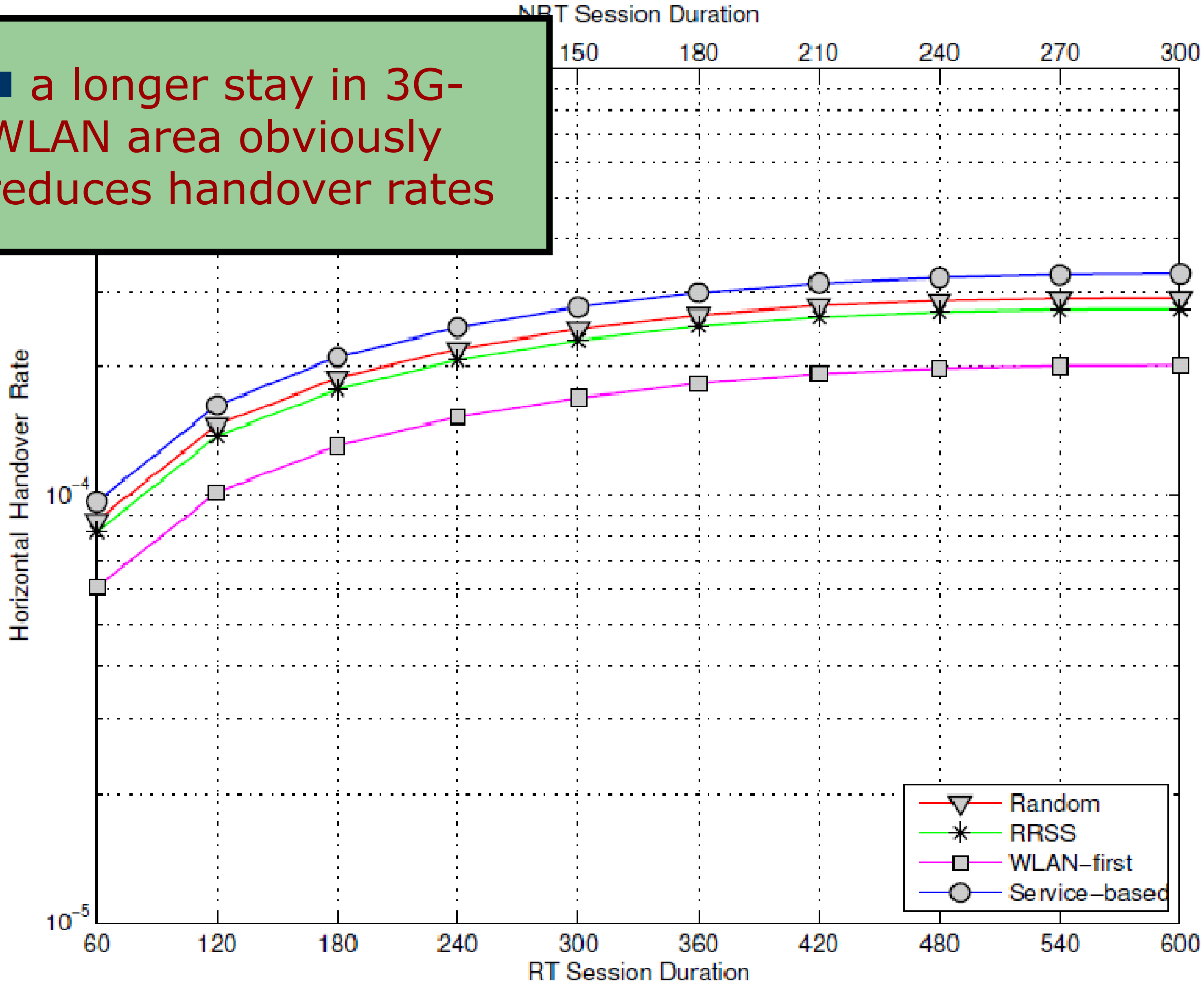
mobility pattern 1 ($t_{3G\text{-}WLAN}$=474, P_{NRT}=P_{RT}=0.5)



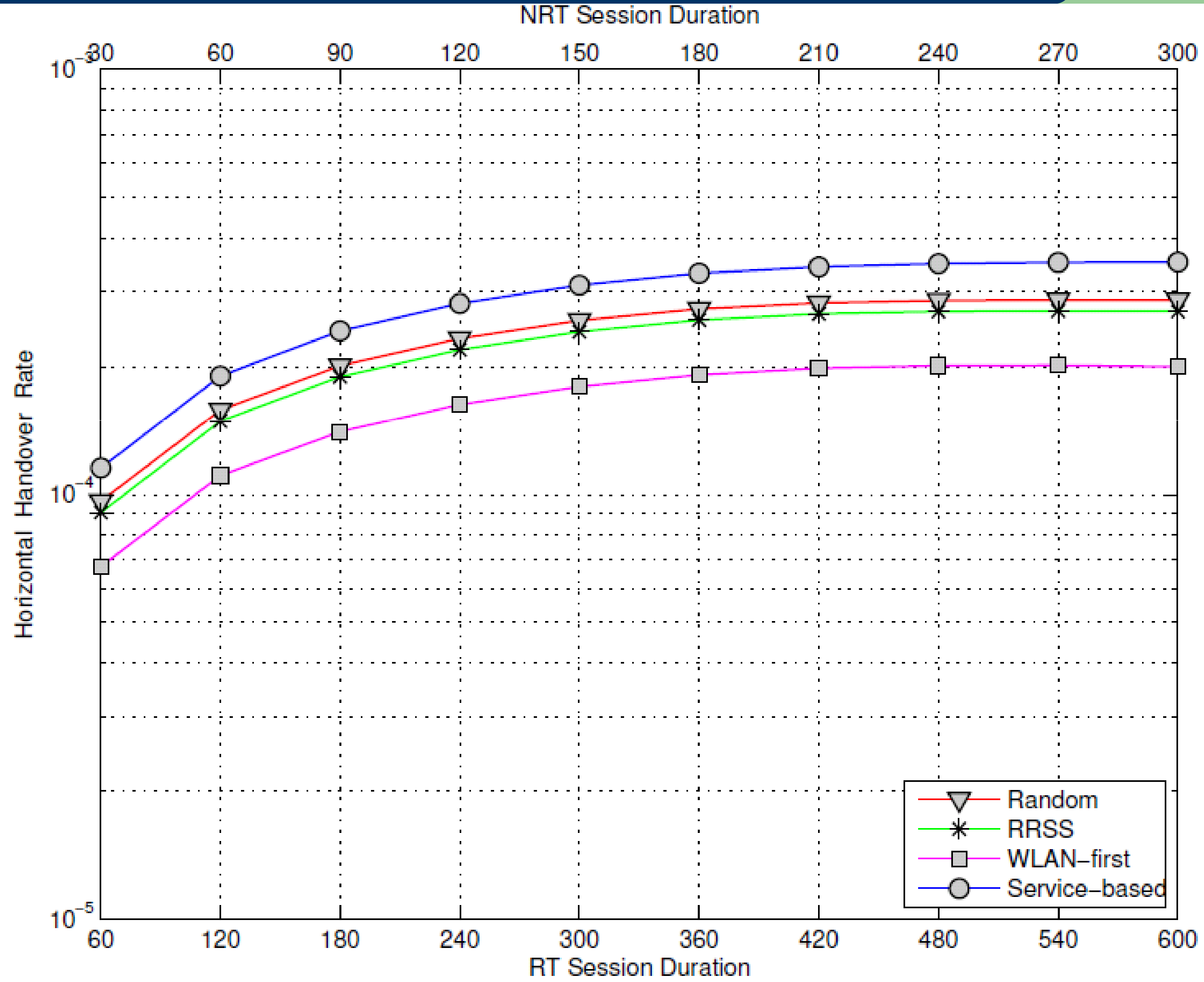
- it depends on the probability of being connected to 3G when moving out a 3G-WLAN compound cell

mobility pattern 2 ($t_{3G\text{-}WLAN}=1200$, $P_{NRT}=P_{RT}=0.5$)

- a longer stay in 3G-WLAN area obviously reduces handover rates



traffic pattern 1 ($t_{3G\text{-}WLAN}$=1200, P_{NRT}=0.3 P_{RT}=0.7)



traffic pattern 2 ($t_{3G\text{-}WLAN}$=1200, P_{NRT}=0.7 P_{RT}=0.3)

- a lower RT probability means less portion of time connected to 3G, thus lower handover rates

- SB is more sensitive than the others, and is now almost the same as random