Timeliness Evaluation of Intermittent Mobile Connectivity over Pub/Sub Systems

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MiMove
Middleware on the Move

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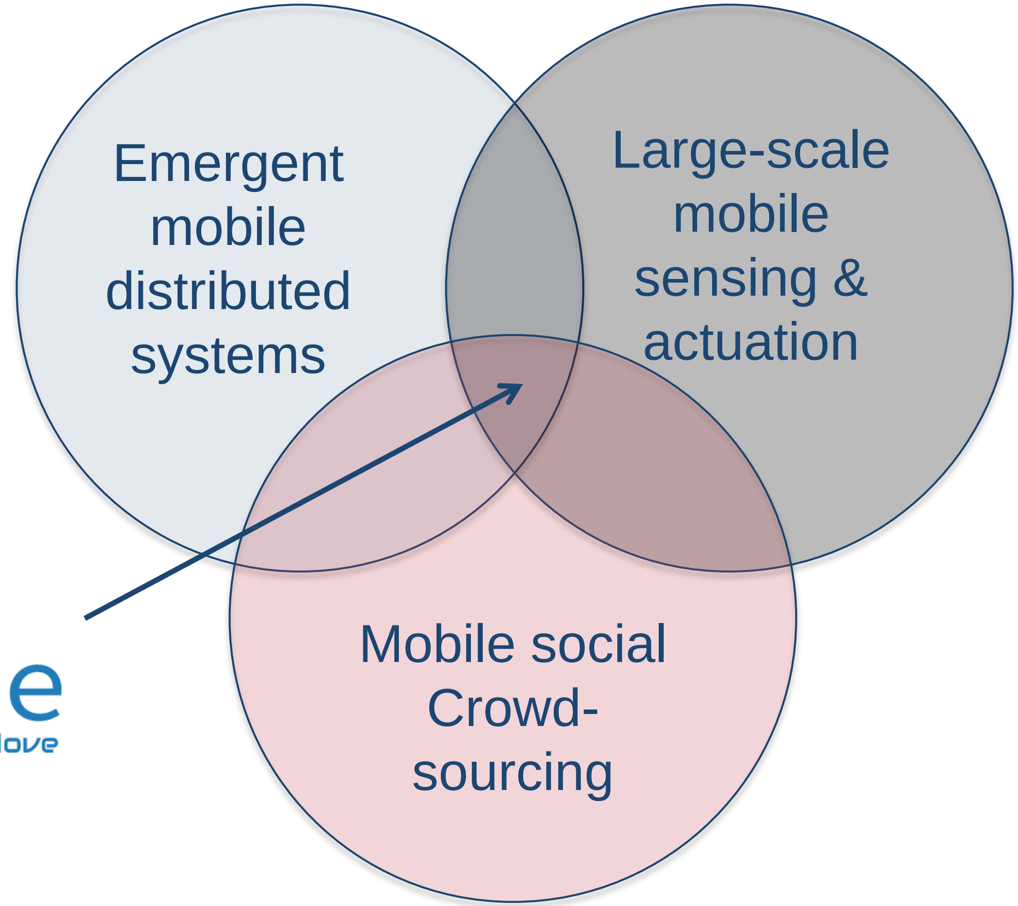
Who am I?

- PhD student, working with Nikolaos Georgantas & Valérie Issarny
- At MiMove (Middleware on the Move) team
- Core Research Areas @MiMove:



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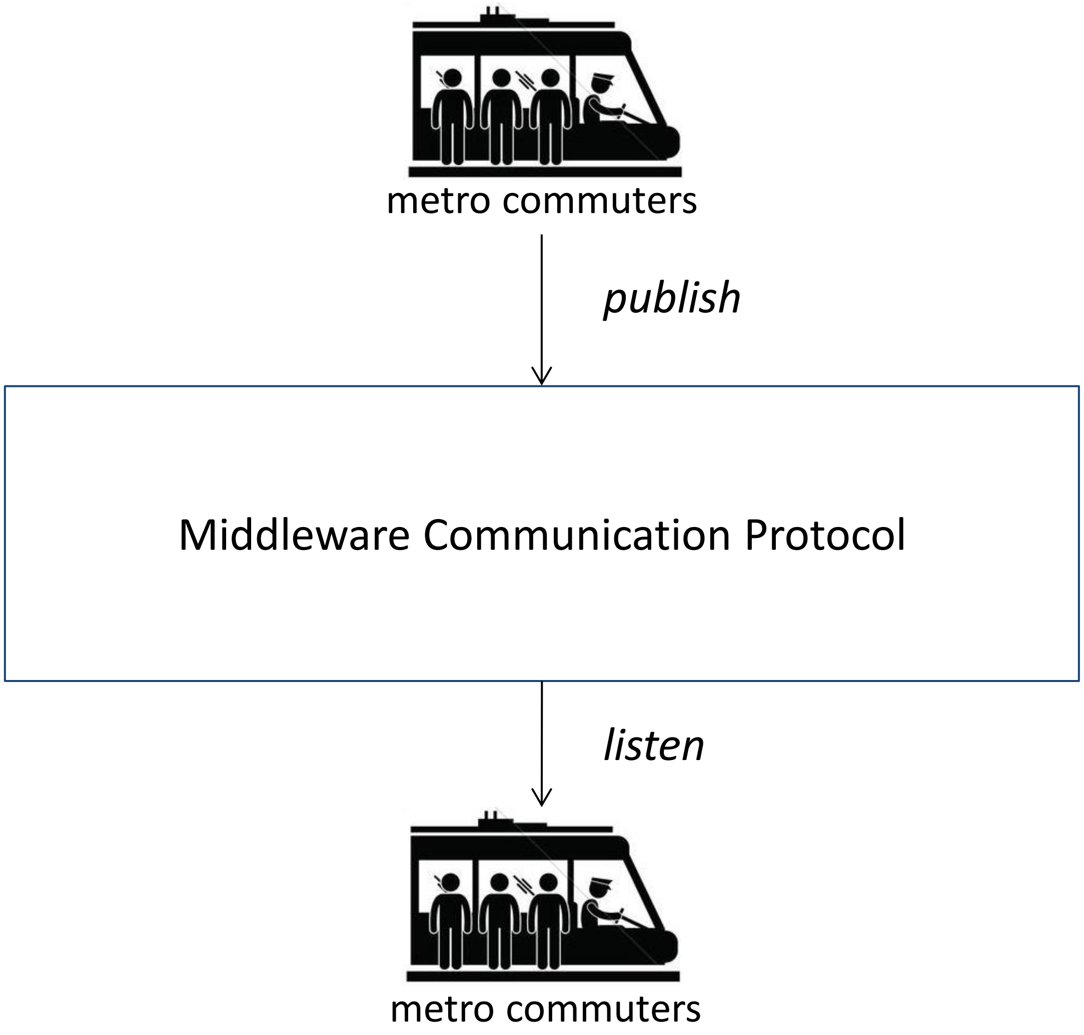
Motivation

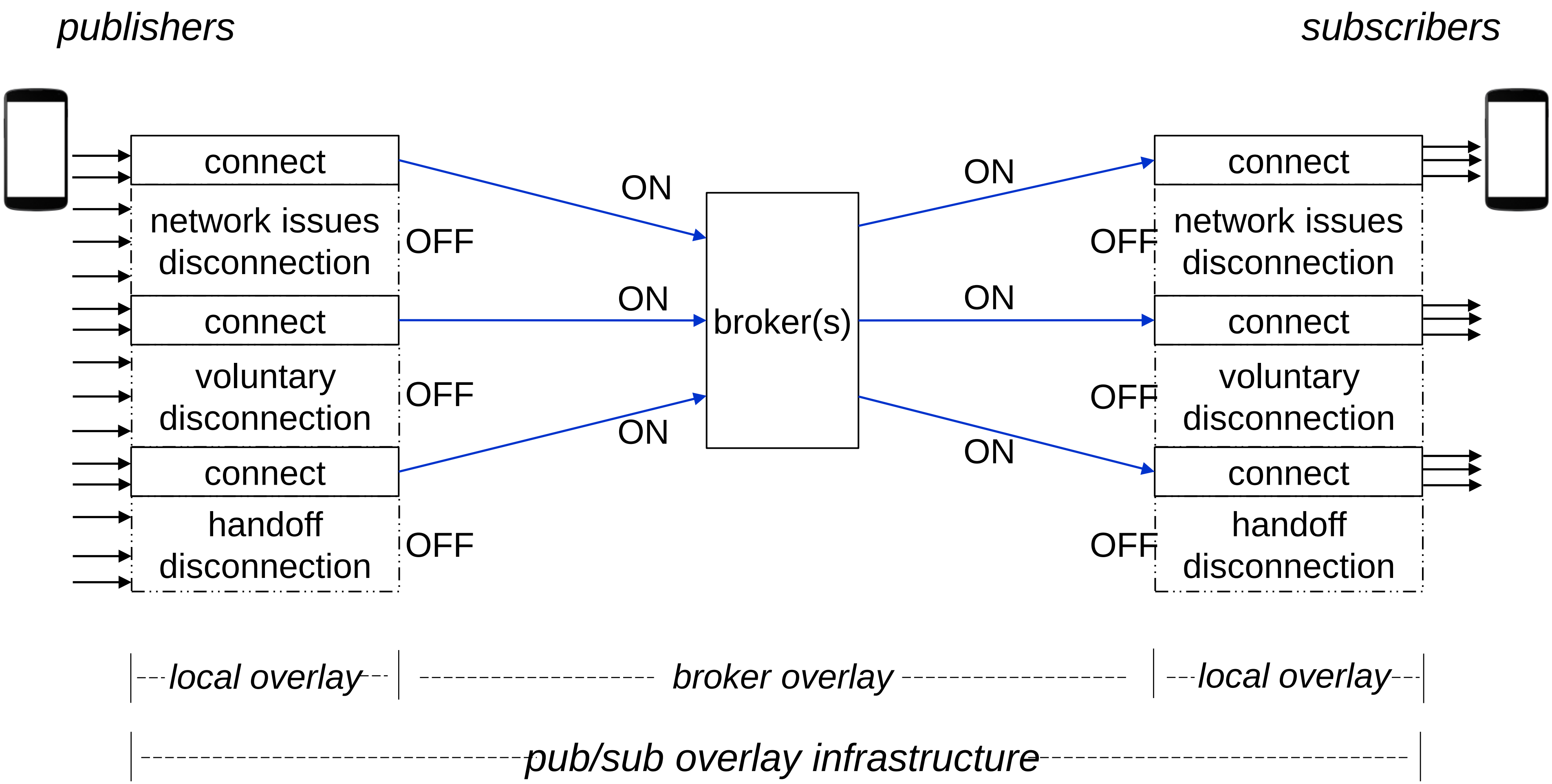


What is the end-to-end response time between metro commuters?

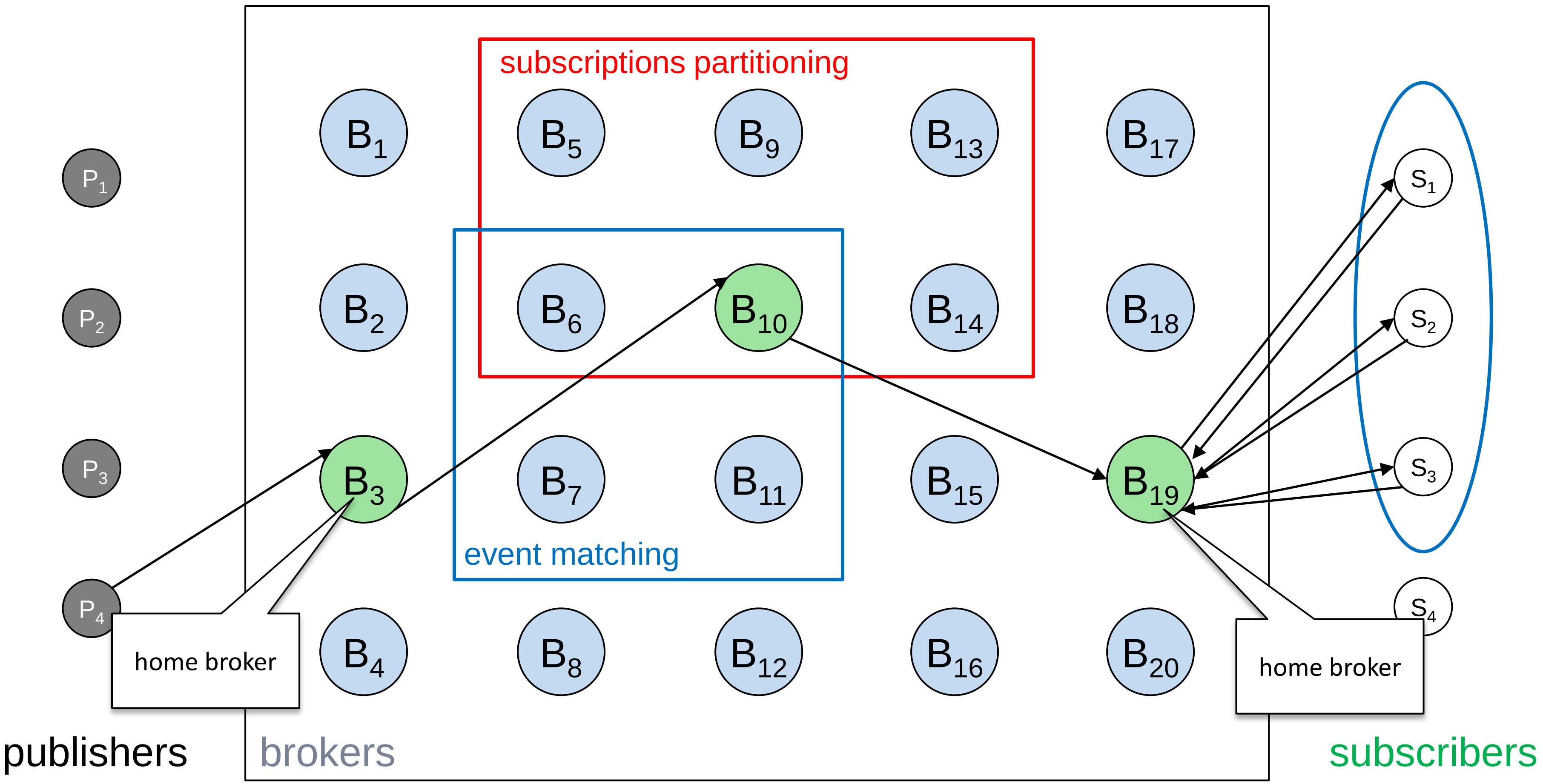
Outline

- System Model:
  - Mobile publish/subscribe (pub/sub) system
  - Pub/sub in wide-scale
- End-to-end Response Time:
  - Queueing modeling
  - ON/OFF queueing center
  - End-to-end delay calculation
- Evaluation:
  - ON/OFF queueing center validation
  - End-to-end System tuning
- Conclusions & Future work

Peer's mobile connectivity behaviour in a (reliable) Pub/Sub system



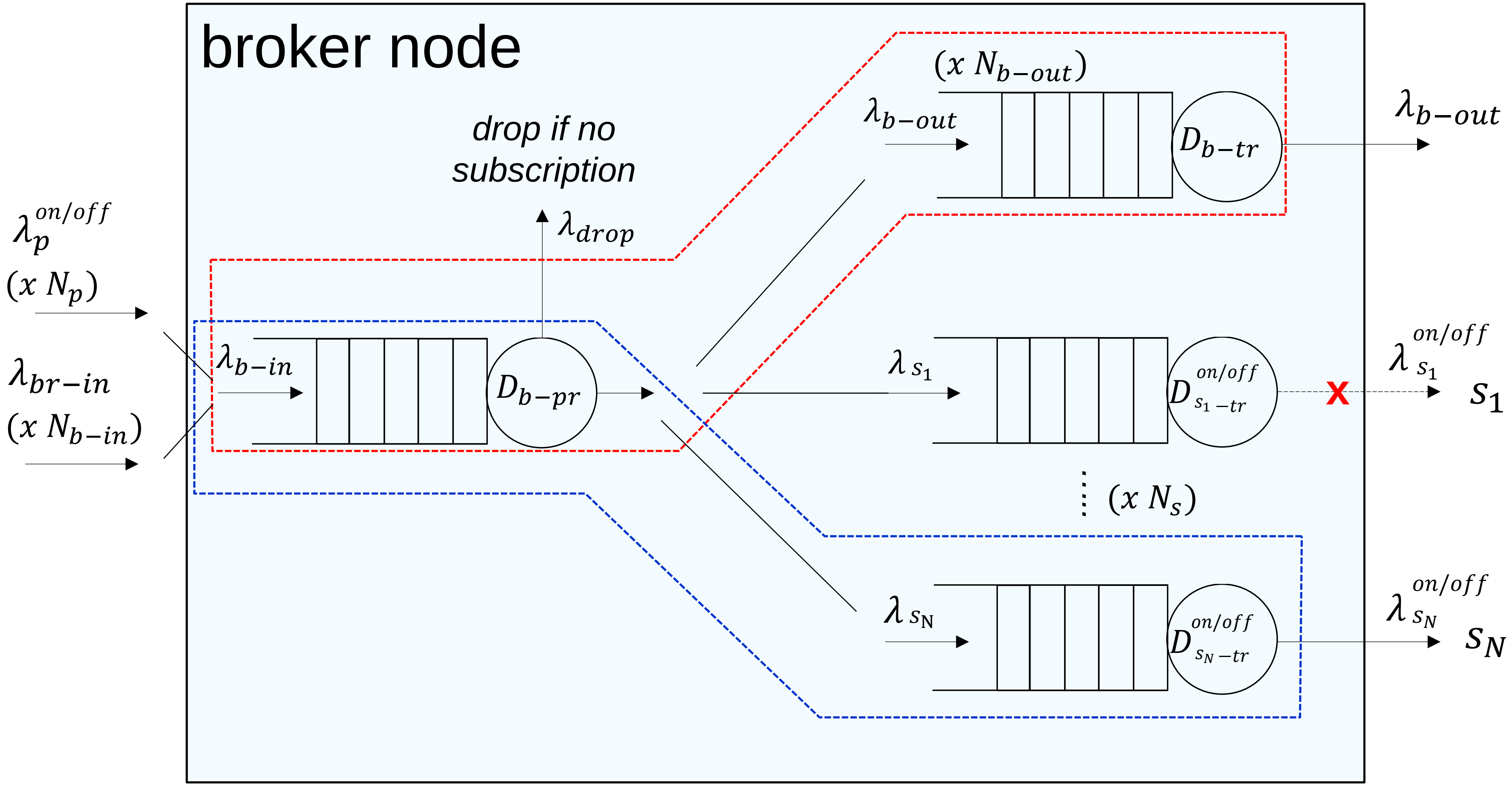
Publish/Subscribe System



event routing process

[1] R. Baldoni et al., "Distributed event routing in publish/subscribe communication systems: a survey," DIS, Universita di Roma La Sapienza, Tech. Rep, 2005.

Publish/Subscribe broker node Queueing Model



Mathematical formulation (1)

What is the end-to-end response time of the events published from each publisher to each subscriber (R_s^p) ?

ON/OFF queueing center model: $q_{\mathrm{on/off}} = (\lambda_{\mathrm{in}}, \lambda_{\mathrm{out}}^{\mathrm{on/off}}, D_{\mathrm{tr}}, \theta_{\mathrm{ON}}, \theta_{\mathrm{OFF}})$

Publisher Model : $p = (id_{\mathrm{p}}, V_{\mathrm{p}}, \lambda_{\mathrm{p\_in}}, \lambda_{\mathrm{p\_out}}, D_{\mathrm{tr}}^{\mathrm{on/off}}, T_{\mathrm{ON}}, T_{\mathrm{OFF}})$

Subscriber Model : $s = (id_{\mathrm{s}}, V_{\mathrm{s}}, \lambda_{\mathrm{s\_in}}, D_{\mathrm{pr}}, T_{\mathrm{ON}}, T_{\mathrm{OFF}})$

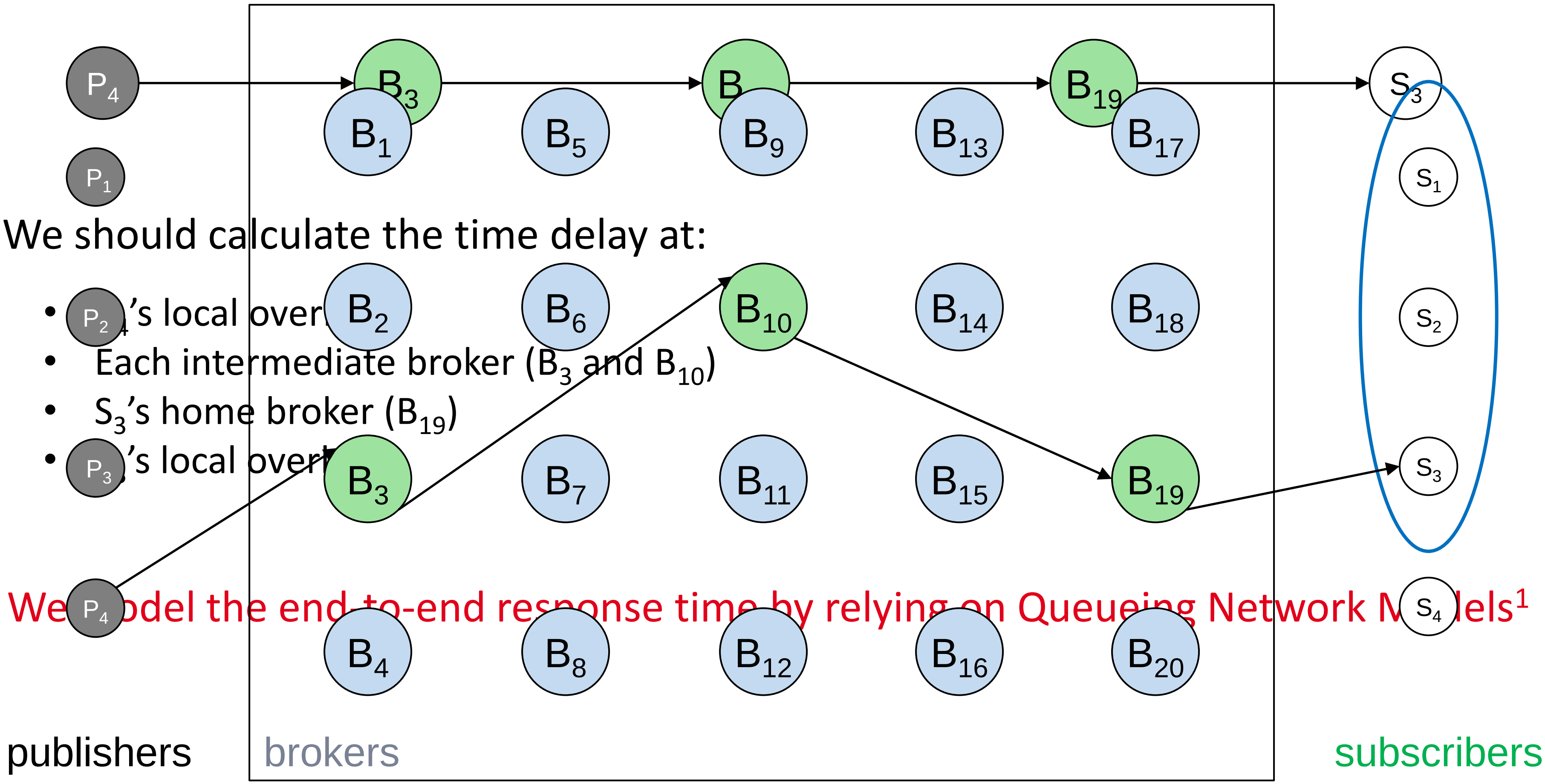
Broker Model : $b = (id_{\mathrm{b}}, \lambda_{\mathrm{b\_in}}, D_{\mathrm{pr}}, N_{\mathrm{s}}, D_{\mathrm{s}}^{on/off}, \lambda_{\mathrm{s\_out}}, N_{\mathrm{b\_out}}, D_{\mathrm{b\_tr}}, \lambda_{\mathrm{b\_out}})$

System model assumptions:

- For each V, events are produced according to a Poisson process
- λ, D and θ_{ON}, θ_{OFF} are exponentially distributed
- Reliable message transmissions
- FIFO Event ordering
- Persistent subscriptions (compared to ON/OFF periods)
- Sufficient queue capacity

Mathematical formulation (2)

What is the end-to-end response time from p_4 to s_3?



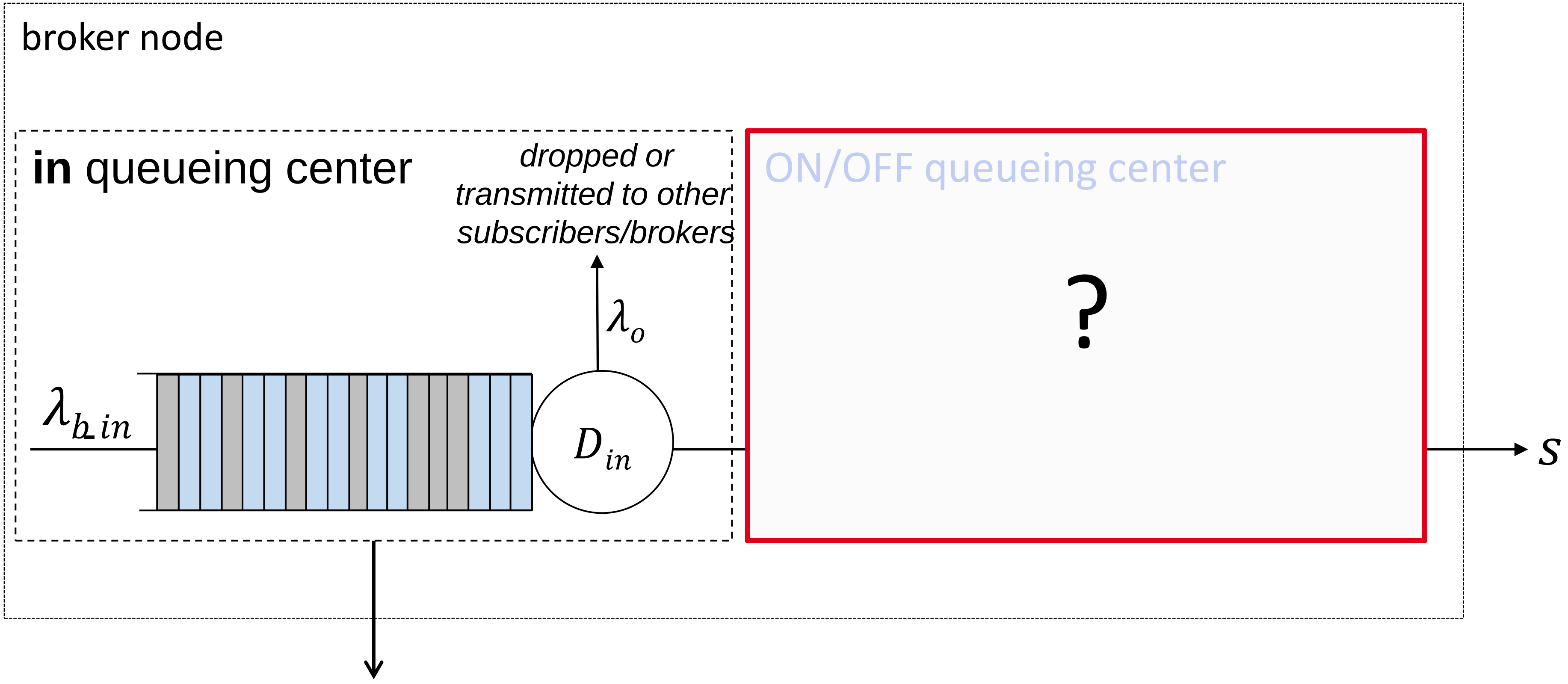
We should calculate the time delay at:

- $_4$'s local over
- Each intermediate broker (B_3 and B_{10})
- S_3's home broker (B_{19})
- 's local overl

We model the end-to-end response time by relying on Queueing Network Models[1]

[1] E. Lazowska et al., Quantitative system performance: computer system analysis using queueing network models. Prentice-Hall, Inc., 1984.

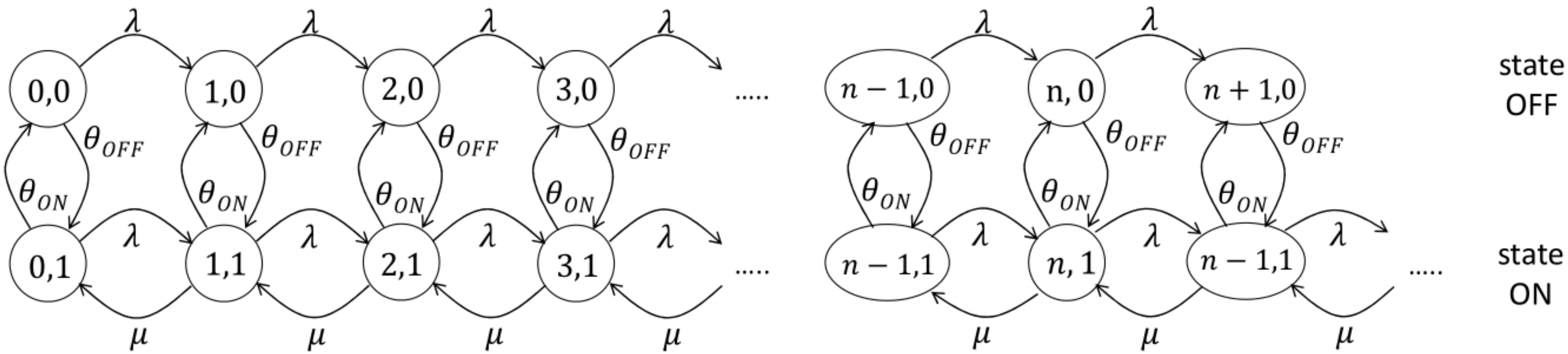
Home Broker delay calculation



$$R_s^{in} = \frac{D_{in}}{1 - \lambda_{b\_in} D_{in}}$$

Possible solutions

- 2-D Markov chain:
  - solving the global balance equations[1]

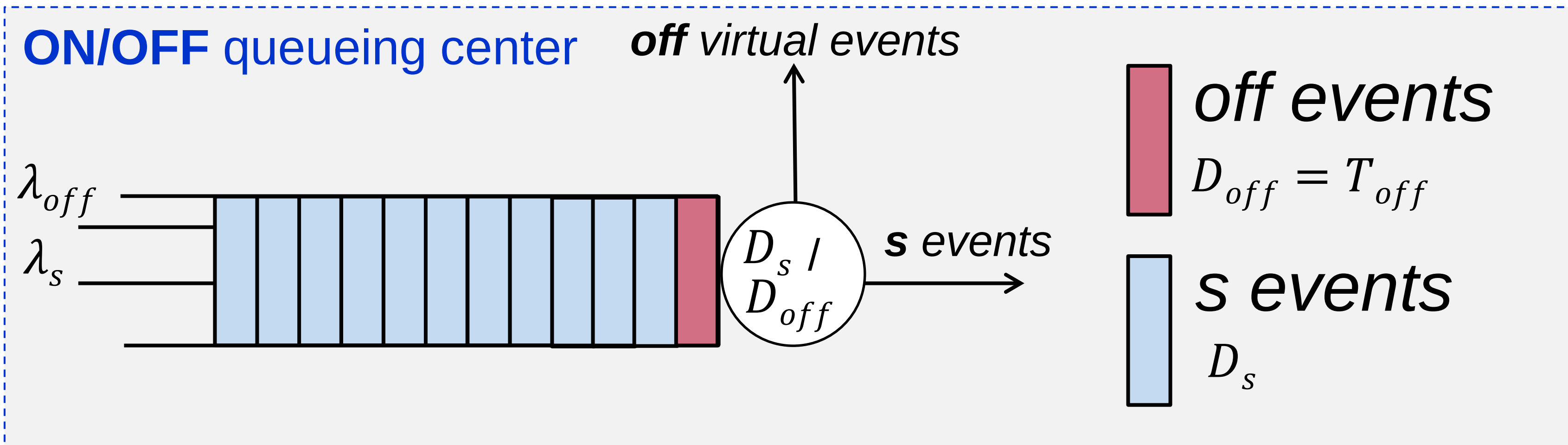


- Mean Value Approach

[1] G. Bouloukakis et al., Performance Modeling of the Middleware Overlay Infrastructure of Mobile Things. IEEE International Conference on Communications, 2017

ON/OFF queueing center delay calculation

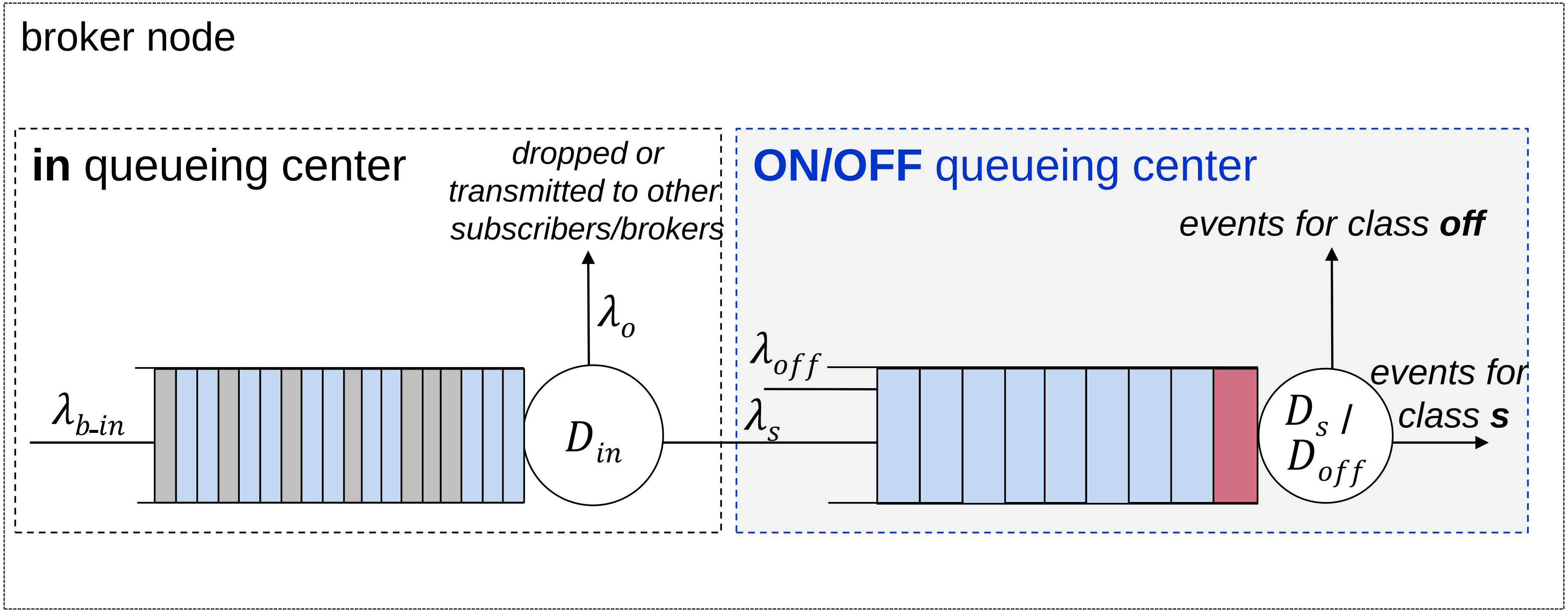
- Mean Value Approach:
  - 2-class queueing center with ‘off’ and ‘normal’ events
  - model T_{OFF} intervals as arrivals of ‘off’ events
  - ‘off’ events have preemptive priority over normal events



$$R_s^{on/off} = \frac{\frac{T_{OFF}^2}{T_{ON} + T_{OFF}} + D_s \frac{T_{ON} + T_{OFF}}{T_{ON}}}{1 - \lambda_s D_s \frac{T_{ON} + T_{OFF}}{T_{ON}}}$$

[2] G. Bouloukakis et al., Timeliness Evaluation of Intermittent Mobile Connectivity over Pub/Sub Systems. 8th ACM/SPEC International Conference on Performance Engineering (ICPE), 2017

Home Broker Delay Calculation



$$R_{\mathrm{s}}^{\mathrm{in}} = \frac{D_{\mathrm{in}}}{1 - \lambda_{\mathrm{b\_in}} D_{\mathrm{in}}} \quad + \quad R_{\mathrm{s}}^{on/off} = \frac{\frac{T_{\mathrm{OFF}}^2}{T_{\mathrm{ON}} + T_{\mathrm{OFF}}} + D_{\mathrm{s}} \frac{T_{\mathrm{ON}} + T_{\mathrm{OFF}}}{T_{\mathrm{ON}}}}{1 - \lambda_{\mathrm{s}} D_{\mathrm{s}} \frac{T_{\mathrm{ON}} + T_{\mathrm{OFF}}}{T_{\mathrm{ON}}}}$$

Composition of the end-to-end queueing network from *p* to *s*

Algorithm 1: Composition of end-to-end queueing network publisher p to subscriber s.

Input: path of connected brokers $K \in B$ from p to s; rate of events λ_{ps}, λ_{oth}; and service demand D at p, s and each broker in K.

Output: end-to-end queueing network QN from p to s, λ_k at each queueing center; effective service demand D^k_{eff} at each queueing center.

Connect the publisher's queueing center::

$QN \leftarrow q_{on/off}$;

$\lambda_0 \leftarrow \lambda_{ps}$, $D^0_{eff} \leftarrow D^{ps}_{eff}(\lambda^P_{oth}, D^P)$;

for $k \leftarrow 1$ *to* K **do**

  if $k = K$ **then**

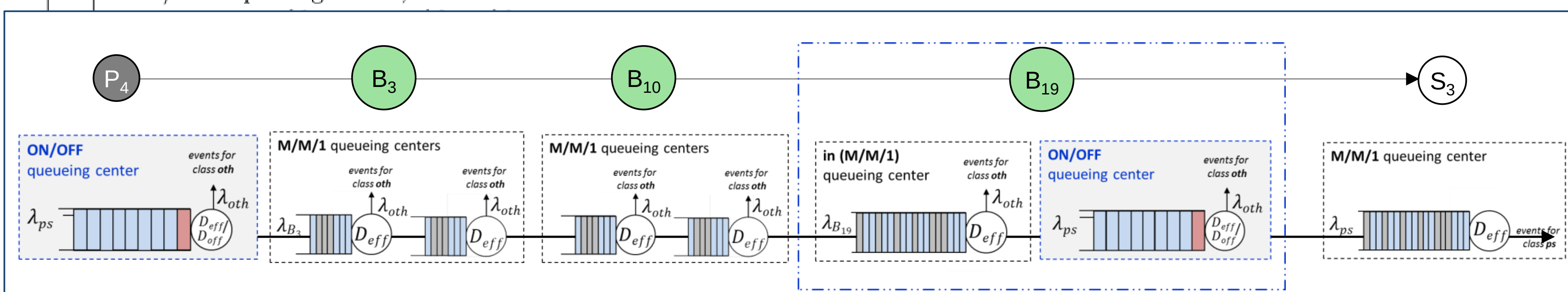
    Connect the queueing centers of s's home broker:

    $QN \leftarrow QN + q_{m/m/1} + q_{on/off}$;

    M/M/1 queuing center;

    $\lambda_{k1} \leftarrow \lambda_{ps}$ $D^{k1}_{eff} \leftarrow D^{ps}_{eff}(\lambda^{k1}_{oth}, D^{k1})$;

    ON/OFF queuing center;



$\lambda_{k+1} \leftarrow \lambda_{ps}$, $D_{eff} \leftarrow D_{eff}(\lambda_{oth}, D$ ...);

return QN, λ_k $\forall k \in \{0, K, k+1\}$, D_k $\forall k \in \{0, K, k+1\}$;

1. *Input*: path of connected brokers from p_4 to s_3; D for each node
2. End-to-end Queueing Network from p_4 to s_3:
   - $q_{on/off}$ for p_4's overlay
   - $q_{m/m/1}$ for intermediate brokers
   - $q_{m/m/1}$ and $q_{on/off}$ for s_3's home broker
   - $q_{m/m/1}$ for s_3's overlay

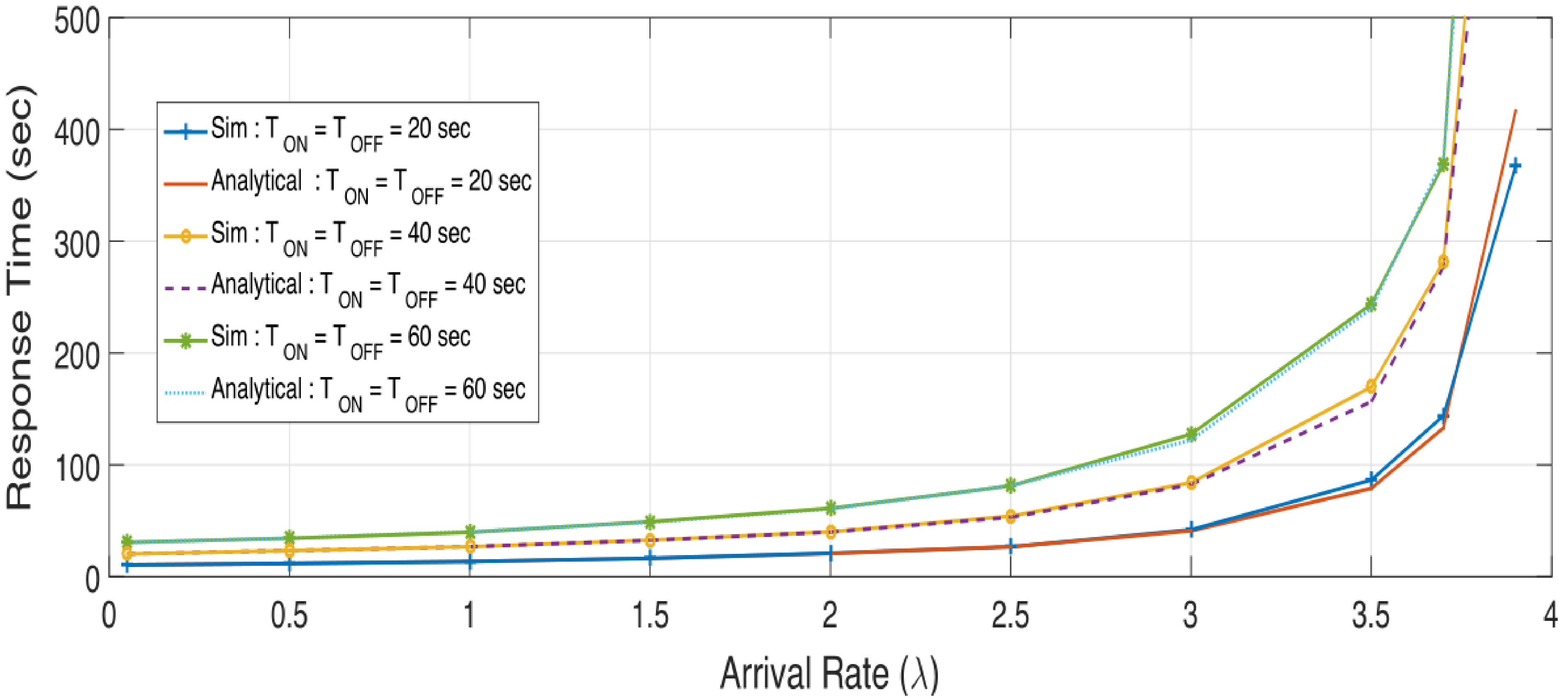
Evaluation Results

- JINQS:
  - open source simulator for Queueing Network Models
- We extend JINQS and we have developed MobileJINQS[1]:

- We validate the ON/OFF queueing center through:
  - probability distributions
  - arrival rates using the D4D dataset
  - ON/OFF connectivity traces collected in the metro of Paris
- Simulate and validate end-to-end response times by considering several disconnection types for each peer (*p* or *s*)

[1] http://xsb.inria.fr/d4d#mobilejinqs

ON/OFF queueing center validation: Estimated vs. Simulated Response Time



D4D Dataset

Orange Data for Development Challenge in Senegal

- D4D Dataset:
  - Generated by Orange labs for the subscribers of Sonatel Network in **Senegal**
  - Contains Call Detail Records (CDRs)
  - Collected over 50 weeks starting from 7th January 2013
  - For every 10 min interval at each antenna, they provide us the number of calls/sms

- CDRs for parameterizing our model[1] we assume that:
  - the arrival load at an antenna (calls/sms) can represent the arrival load of produced events at the publisher's home broker

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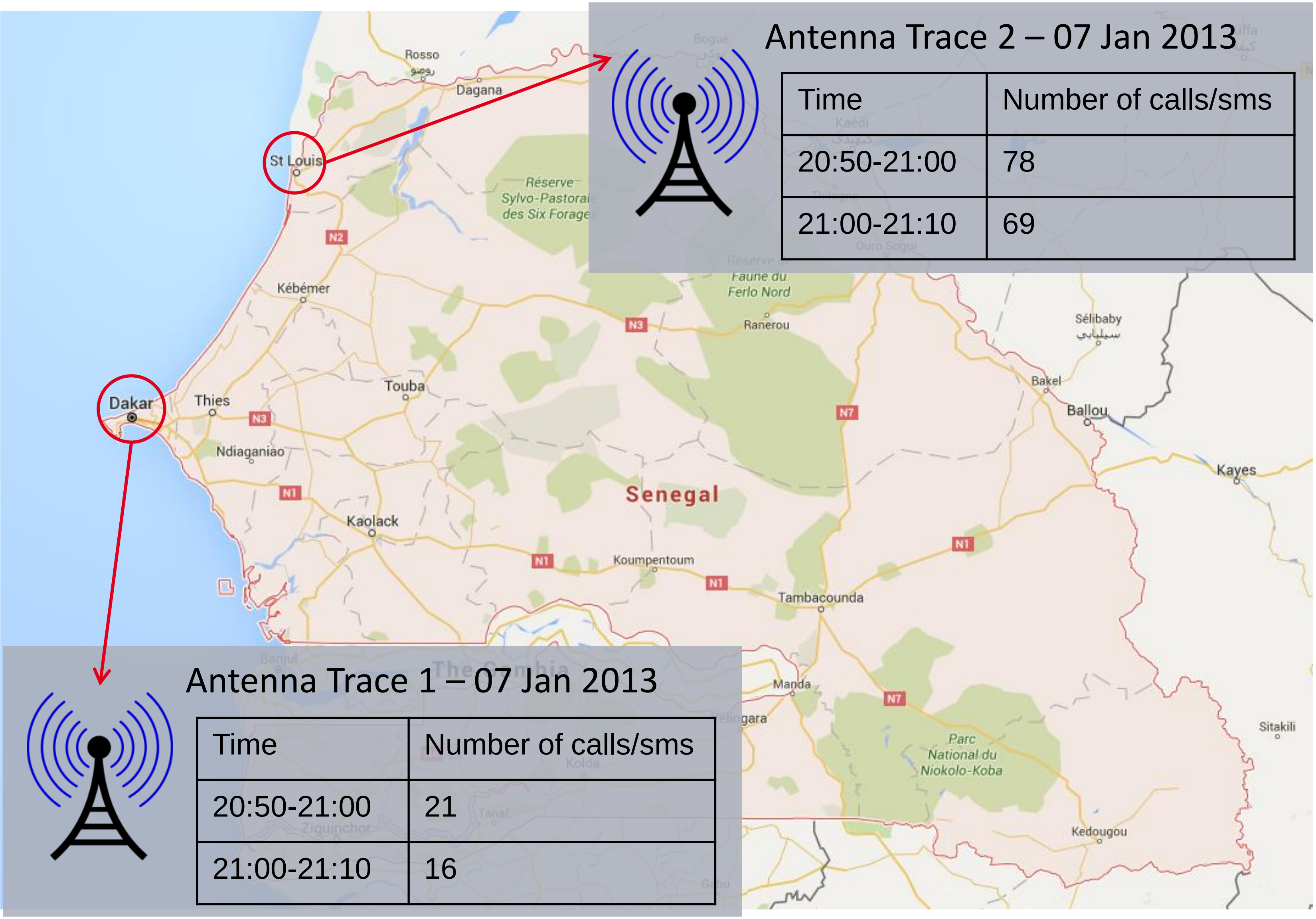
[1] G. Bouloukakis et al., Leveraging CDR datasets for context-rich performance modeling of large-scale mobile pub/sub systems, IEEE WiMob, 2015.

Antenna Real Traces



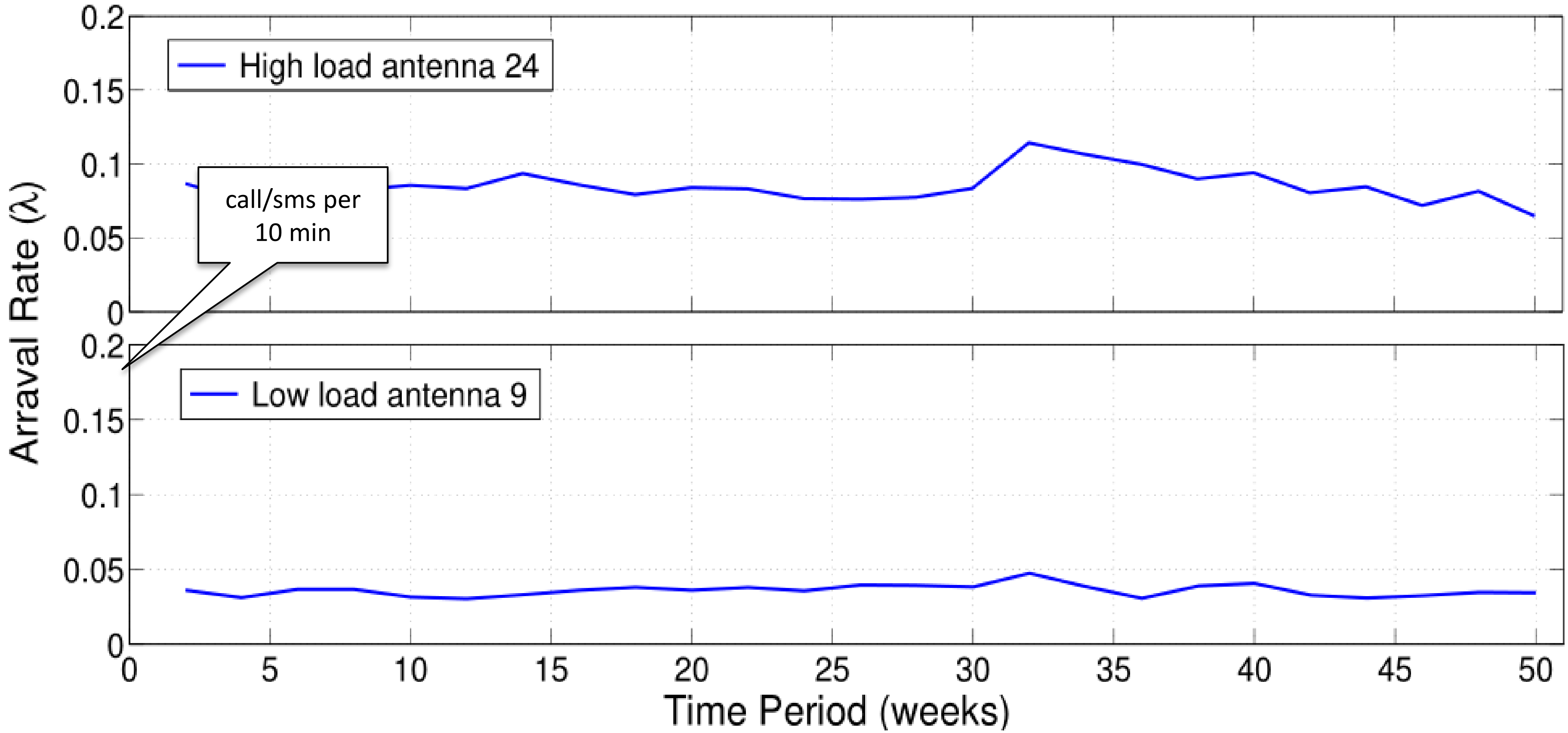
Antenna Trace 2 – 07 Jan 2013

Time	Number of calls/sms
20:50-21:00	78
21:00-21:10	69

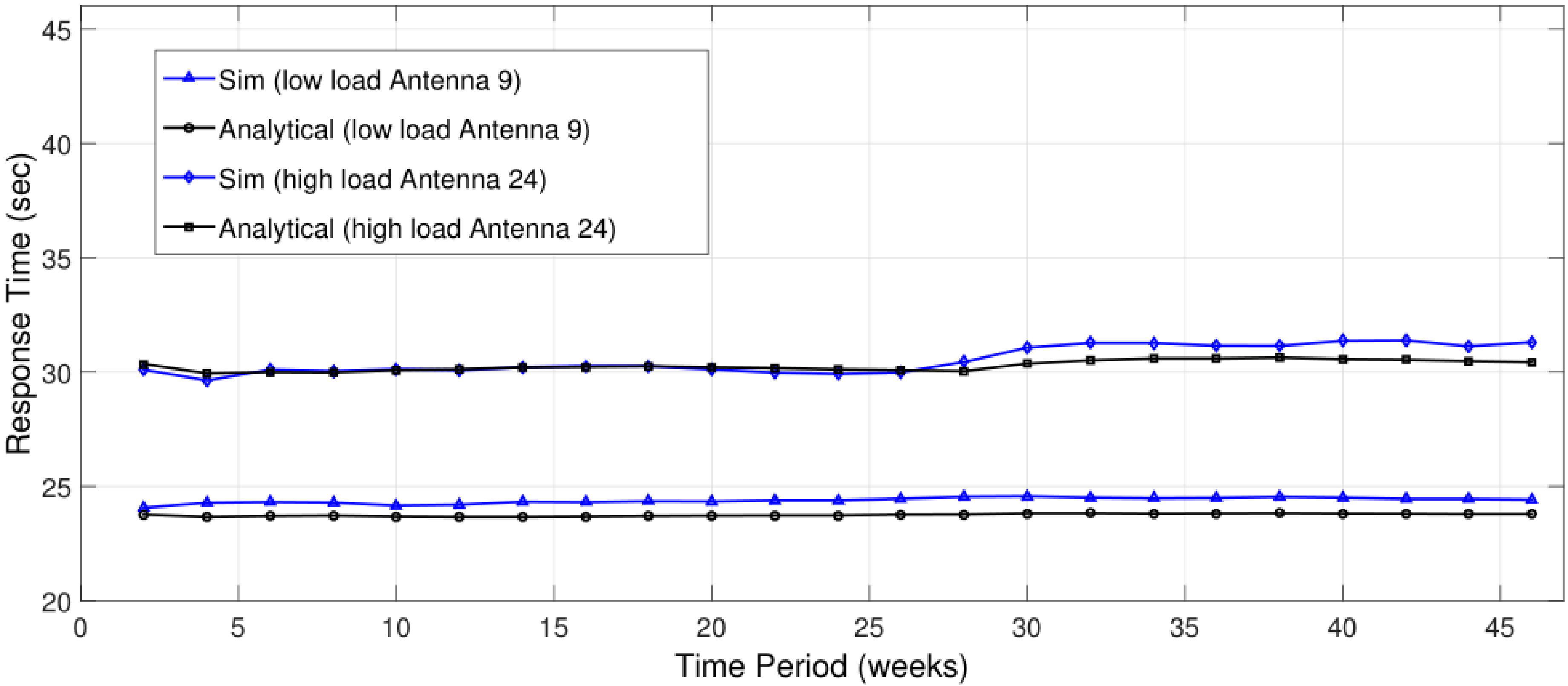
Antenna Trace 1 – 07 Jan 2013

Time	Number of calls/sms
20:50-21:00	21
21:00-21:10	16

ON/OFF Queueing center Validation using Antenna traces (1)

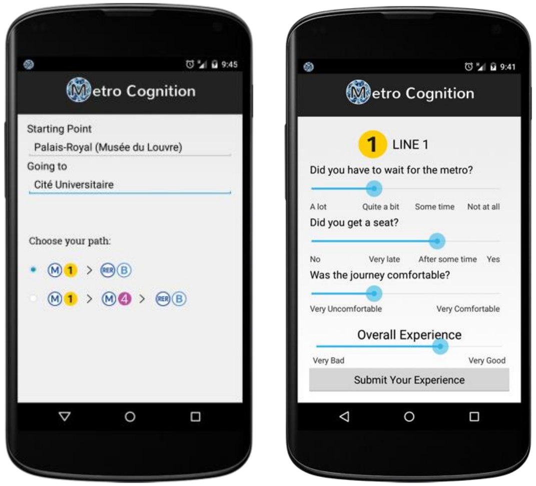


ON/OFF Queueing center Validation using Antenna traces (2)



$$\lambda(t) = \frac{N_i^t}{|t|}$$

Sarathi dataset: Metro Cognition[1] Android Application



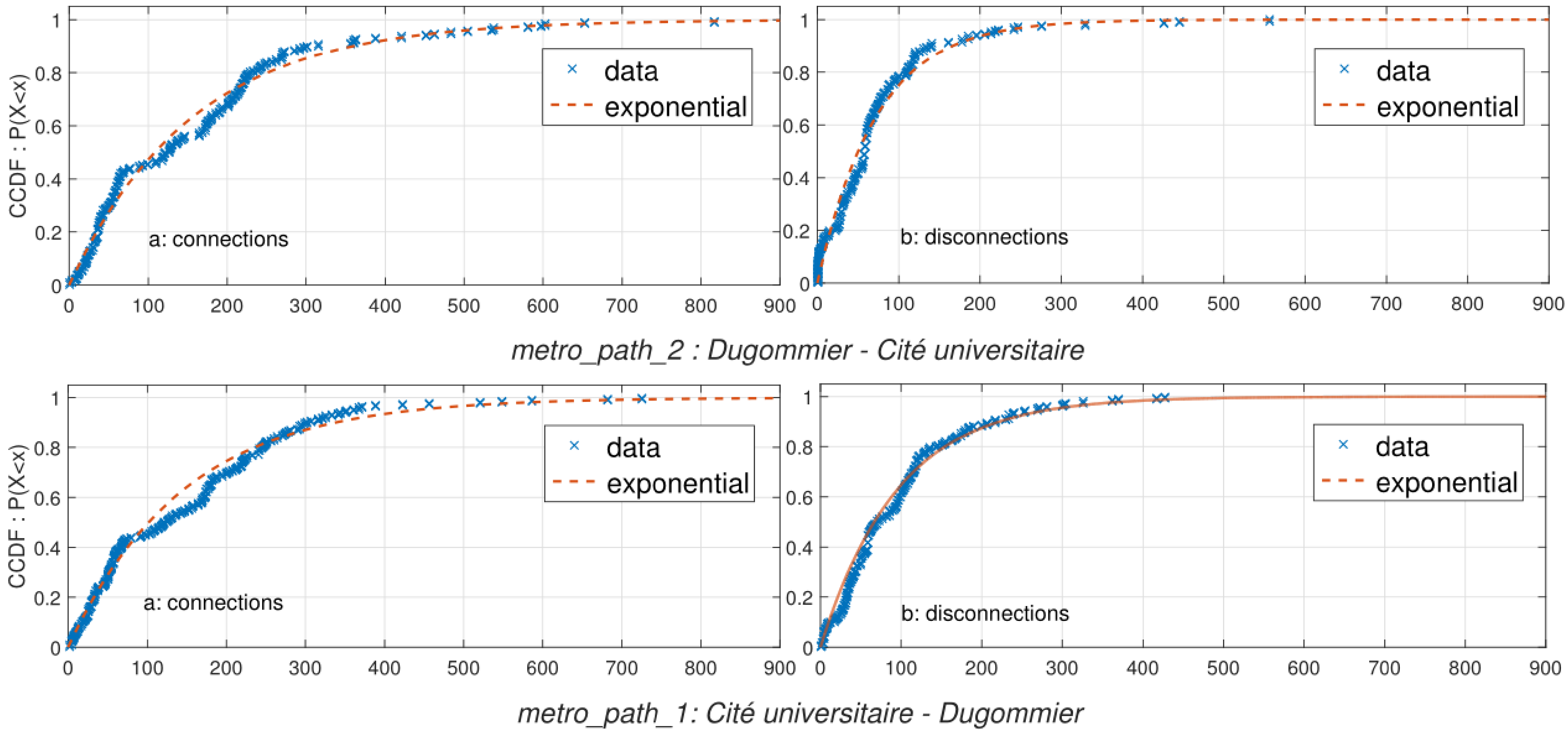
- collects connectivity tuples (*con_tuple*) every 30 seconds using a background service
- each *con_tuple* represents the Internet connectivity status (ON/OFF)
- one connectivity pattern (*con_pattern*) consists of many *con_tuple* in one specific path
- the *GoFlow*[2] pub/sub middleware is used for the data collection

Experimental setup:

- collecting the user's connectivity patterns for a *metro_path_id*
- we concatenate all the *con_patterns* for each *metro_path_id*

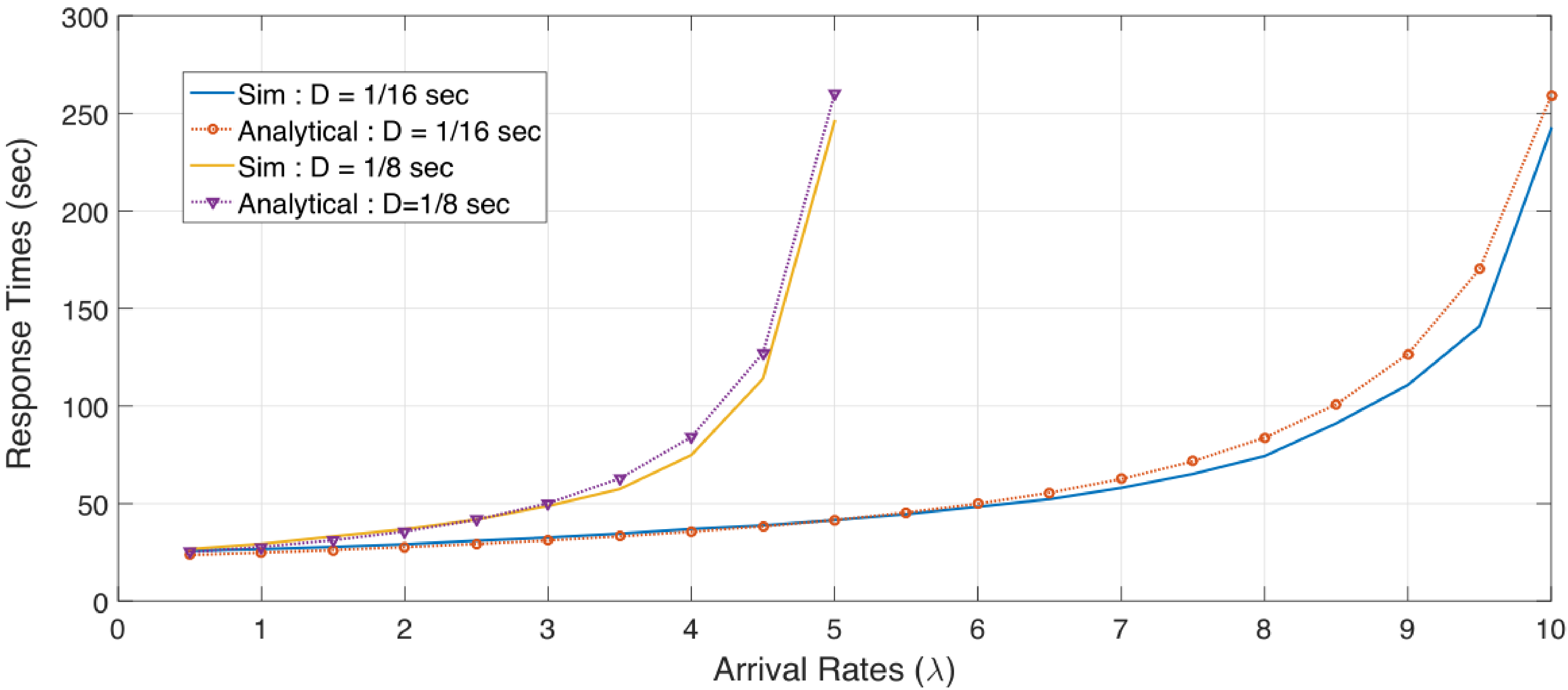
[1] https://play.google.com/apps/testing/edu.sarathi.metroCognition
[2] https://goflow.ambientic.mobi/

ON/OFF QS Validation using Connectivity traces (1)



1. *Cité Universitaire → Dugommier*; journeys : 34; total duration : 15.18 hours; average duration journey : 26.8 min; T_{ON} = 2.43 min and T_{OFF} = 1.6 min.
2. *Dugommier → Cité Universitaire*; journeys : 28; total duration : 12.13 hours; average duration journey : 26 min; T_{ON} = 2.5 min and T_{OFF} = 1.2 min.

ON/OFF QS Validation using Connectivity traces (2)



- 2nd path: *Dugommier → Cité Universitaire*
- For higher rates, there is a quite good match with maximum difference of about 10%.

End-to-end Response Time from *p* to *s*

- We evaluate the response time from *p* to *s*:
  - network issues, voluntary reasons and degraded network
  - 2 intermediate brokers
- Metro travel:
  - Publisher travers: *Étienne Marcel* → *Mairie de Montrouge*, T_{ON} = 4.8 min and T_{OFF} = 1.3 min
  - Subscriber travels: *Cité Universitaire* → *Dugommier*, T_{ON} = 2.58 min and T_{OFF} = 1.2 min
  - less than 60 ms the delay at each intermediate broker
  - 45 sec of end-to-end response time
  - The processing delay in the broker path is negligible

Disconnections	p_4 (T_{ON}, T_{OFF})	s_1 (T_{ON}, T_{OFF})	Simulation	Analytical model	Deviation %
Metro Travel	109, 121.5 (sec)	146.3, 96 (sec)	118.7 (sec)	116.76 (sec)	1.63
	292.1, 78.7 (sec)	155.8, 72.1 (sec)	45.3 (sec)	43.7 (sec)	3.53
Voluntary	60 (sec), 10 (min)	30 (sec), 15 (min)	27.82 (min)	28.31 (min)	1.76
	always, 0	30 (sec), 15 (min)	17.61 (min)	18.03 (min)	2.38
Network Degradation	1 (sec), 1 (sec)	1.5 (sec), 1.5 (sec)	2.41 (sec)	2.26 (sec)	6.22

Conclusion & Next steps

- We present a general approach for the modeling of pub/sub systems supporting mobile peers in wide scale

- Future work:
  - The application of time-to-live lifetime periods to each published event.
  - Deal with unreliable infrastructures for middleware Internet of Things protocols.
  - Introduce models that evaluate the interoperability effectiveness of Things employing heterogeneous protocols.

Thank you