

Timeliness Evaluation of Intermittent Mobile Connectivity over Pub/Sub Systems

**Georgios Bouloukakis¹, Nikolaos Georgantas¹,
Ajay Kattepur² & Valérie Issarny¹**

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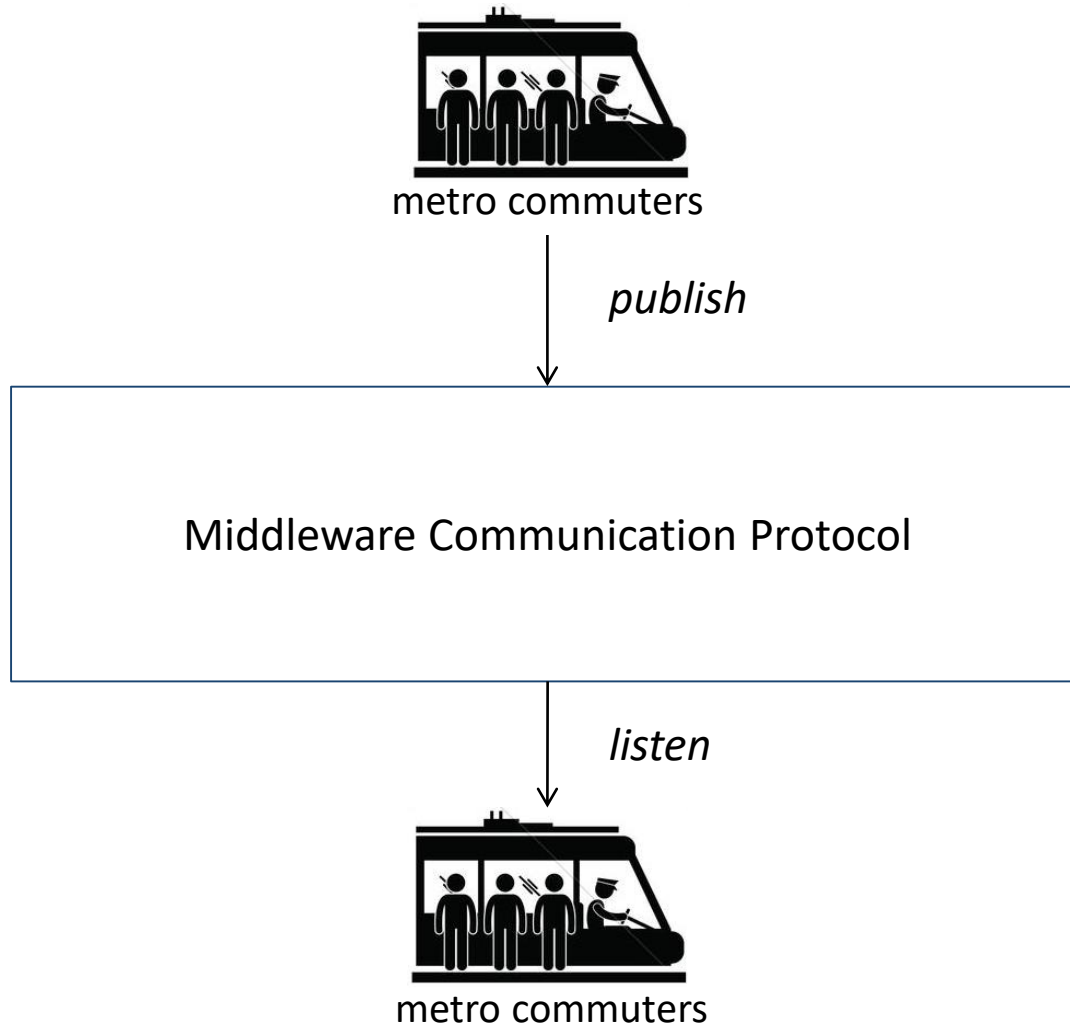
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¹MiMove team, Inria Paris, France

²TCS Research & Innovation, Bangalore, India

MiMove
Middleware on the Move

Motivation



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

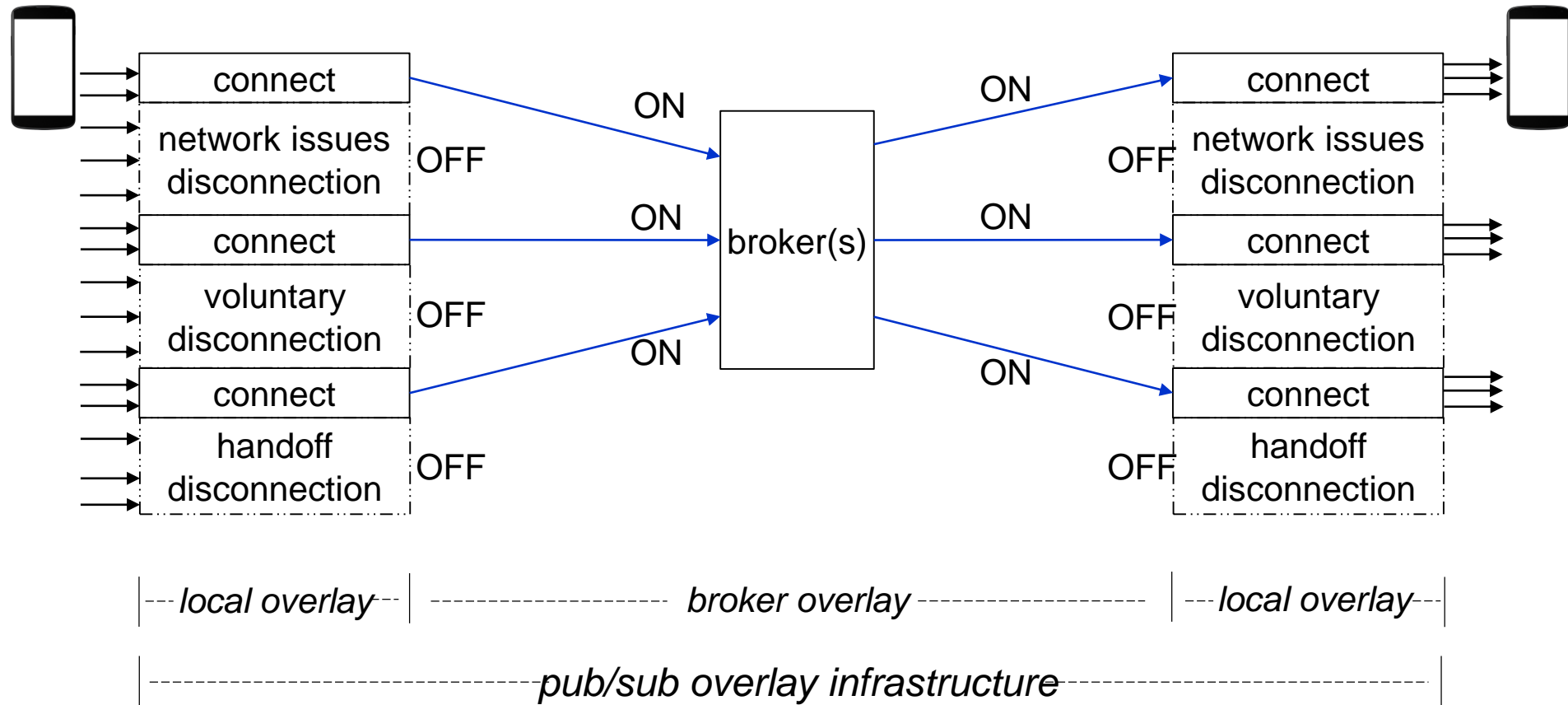
Outline

- 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

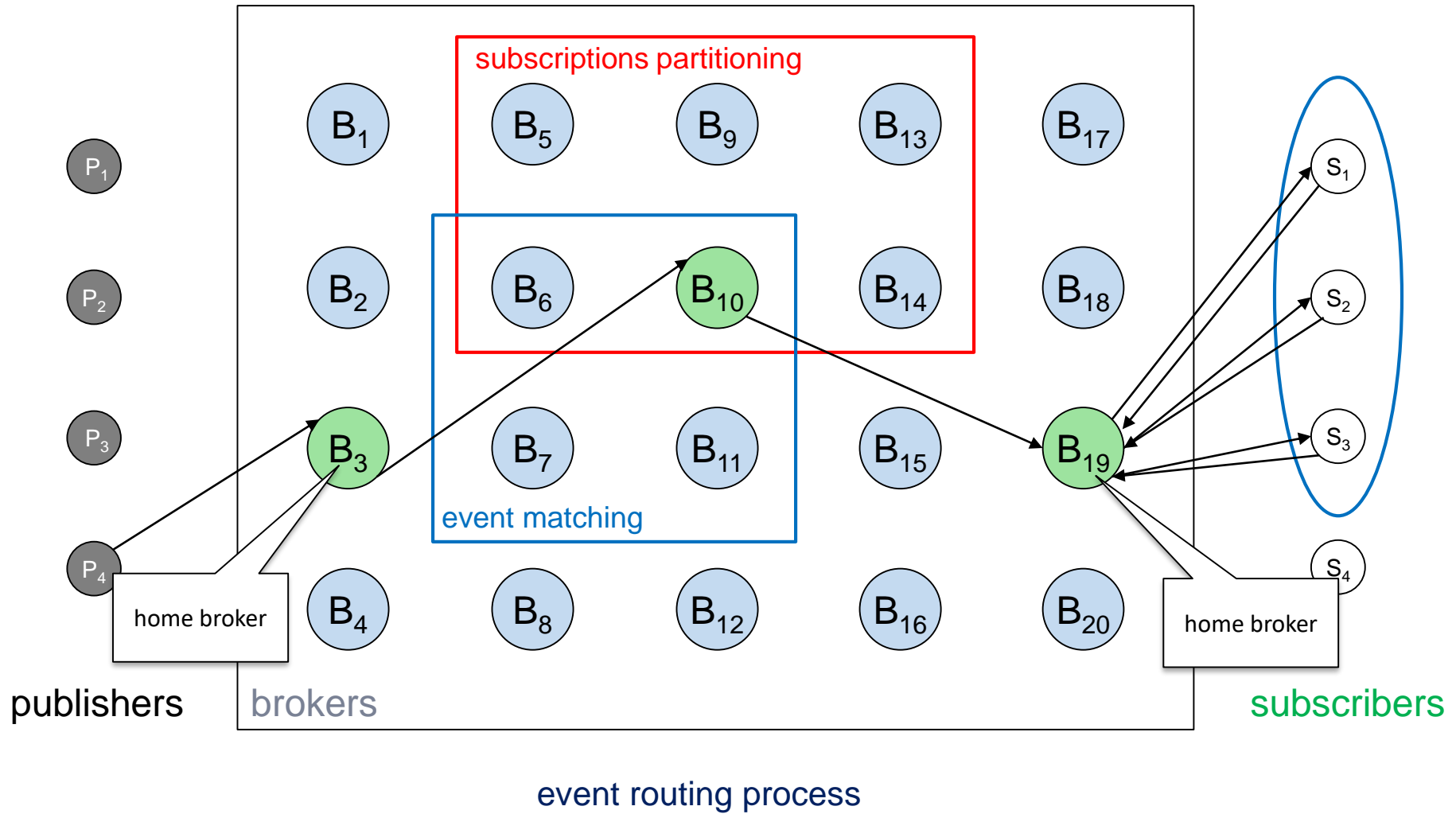
Peer's mobile connectivity behaviour in a Pub/Sub system

publishers

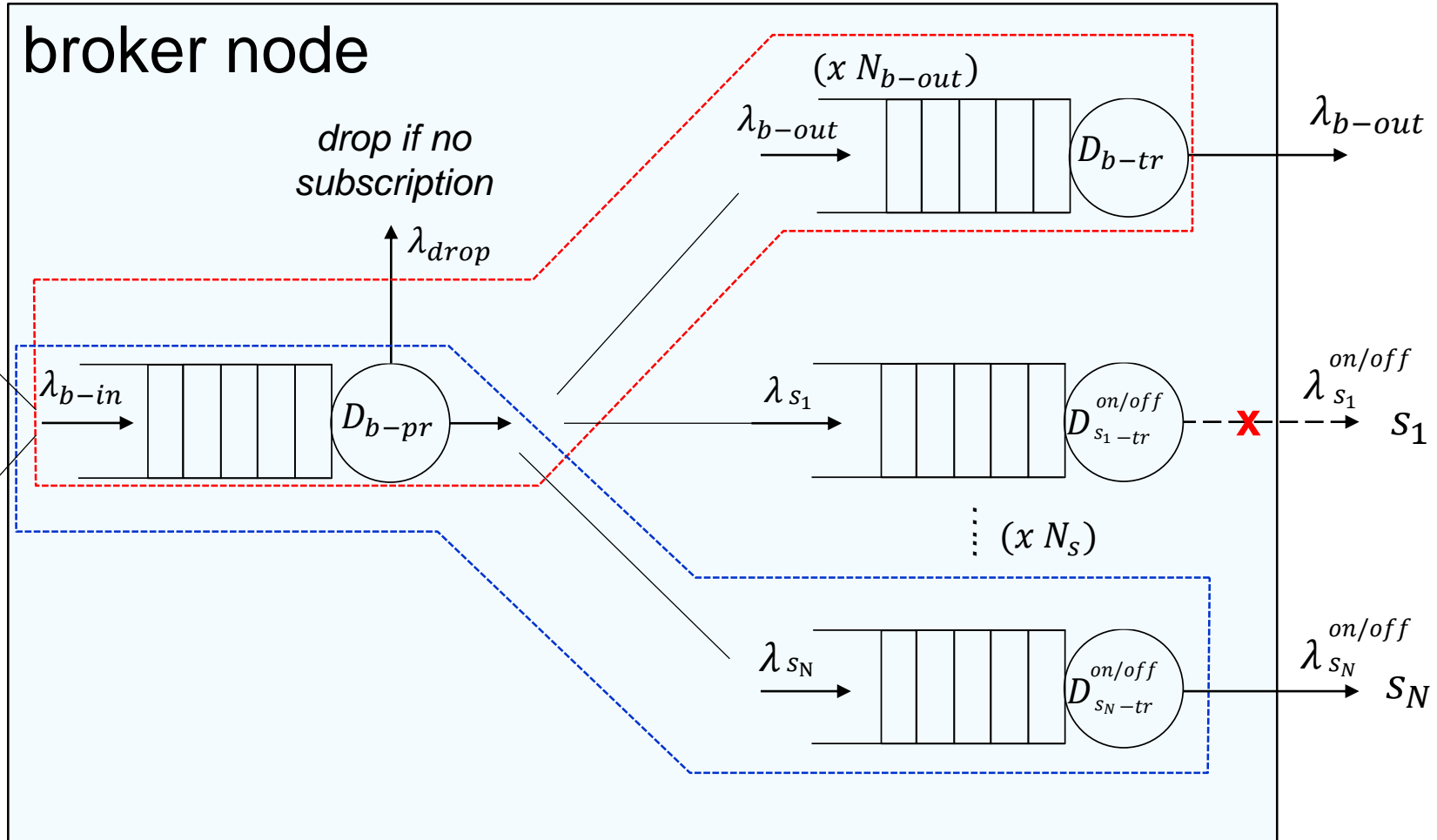
subscribers



Publish/Subscribe System



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

Publisher Model : $p = (id_p, V_p, \lambda_{p_in}, \lambda_{p_out}, D_{tr}^{\text{on/off}}, T_{\text{ON}}, T_{\text{OFF}})$

Subscriber Model : $s = (id_s, V_s, \lambda_{s_in}, D_{pr}, T_{\text{ON}}, T_{\text{OFF}})$

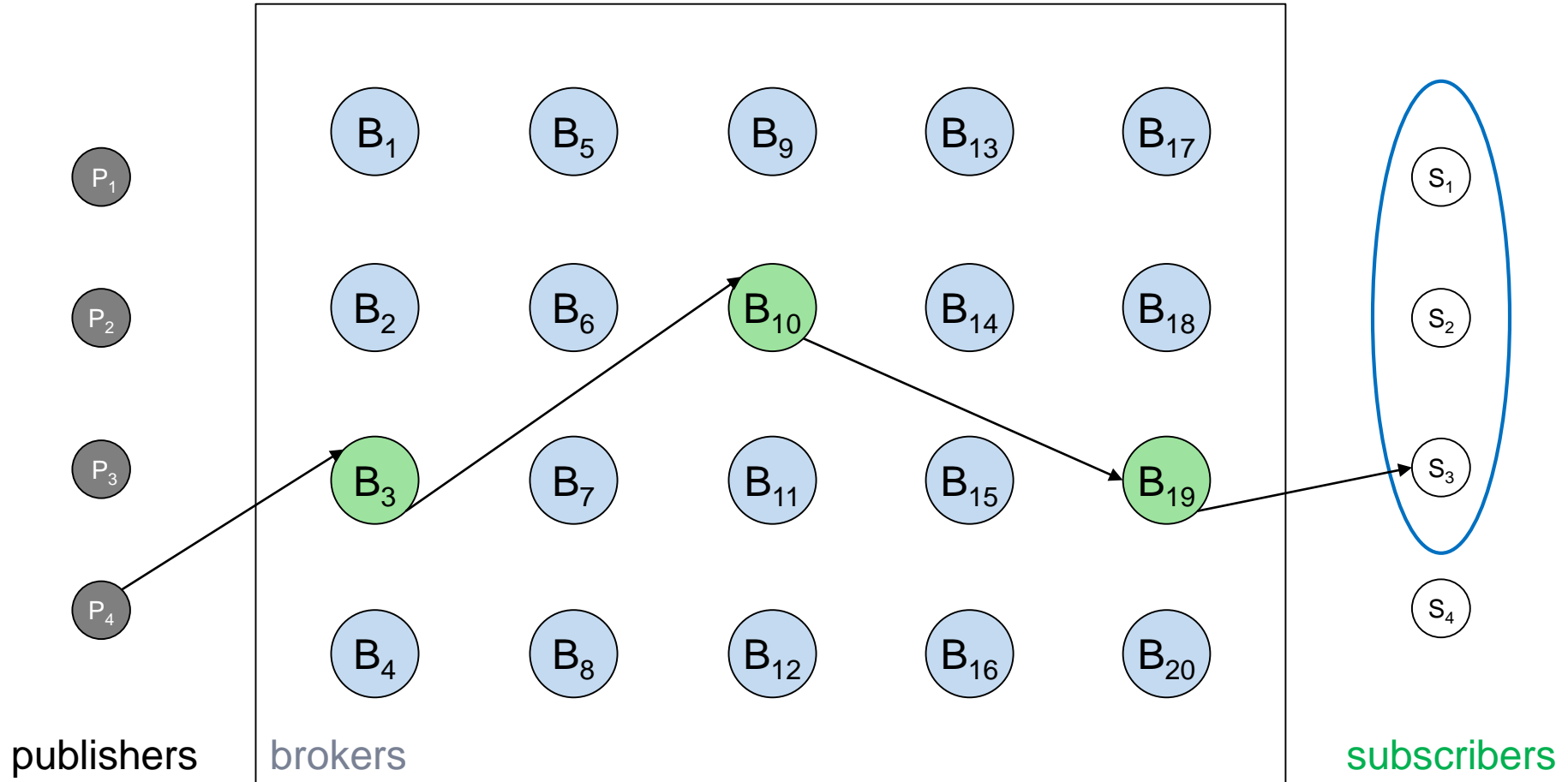
Broker Model : $b = (id_b, \lambda_{b_in}, D_{pr}, N_s, D_s^{\text{on/off}}, \lambda_{s_out}, N_{b_out}, D_{b_tr}, \lambda_{b_out})$

System model assumptions:

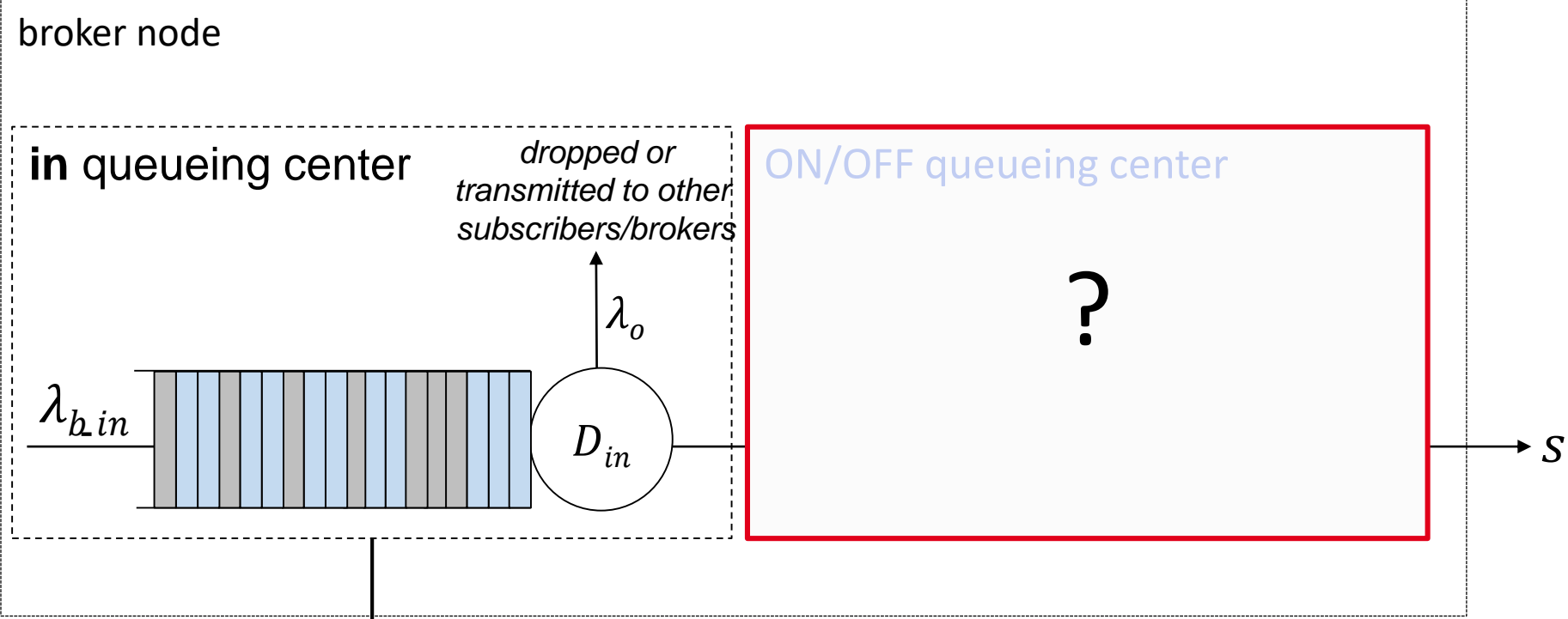
- For each V , events are produced according to a Poisson process
- λ , D and $\theta_{\text{ON}}, \theta_{\text{OFF}}$ are exponentially distributed
- Reliable message transmissions
- FIFO Event ordering
- Persistent subscriptions (compared to ON/OFF periods)
- Sufficient queue capacity

Mathematical formulation (2)

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



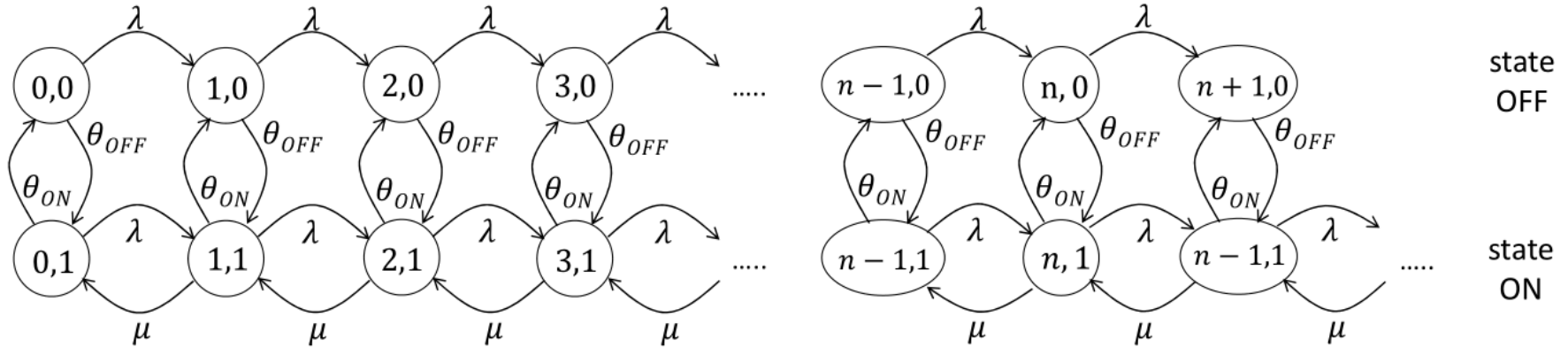
Home Broker delay calculation



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

Possible solutions

- 2-D Markov chain:
 - solving the global balance equations¹

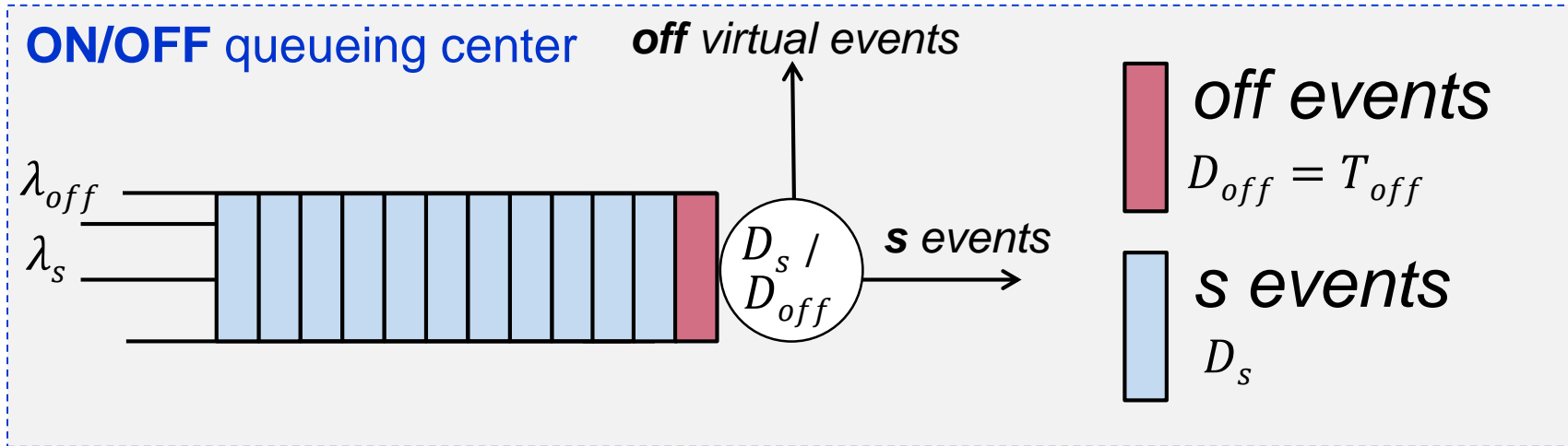


- Mean Value Approach

ON/OFF queueing center delay calculation

➤ Mean Value Approach:

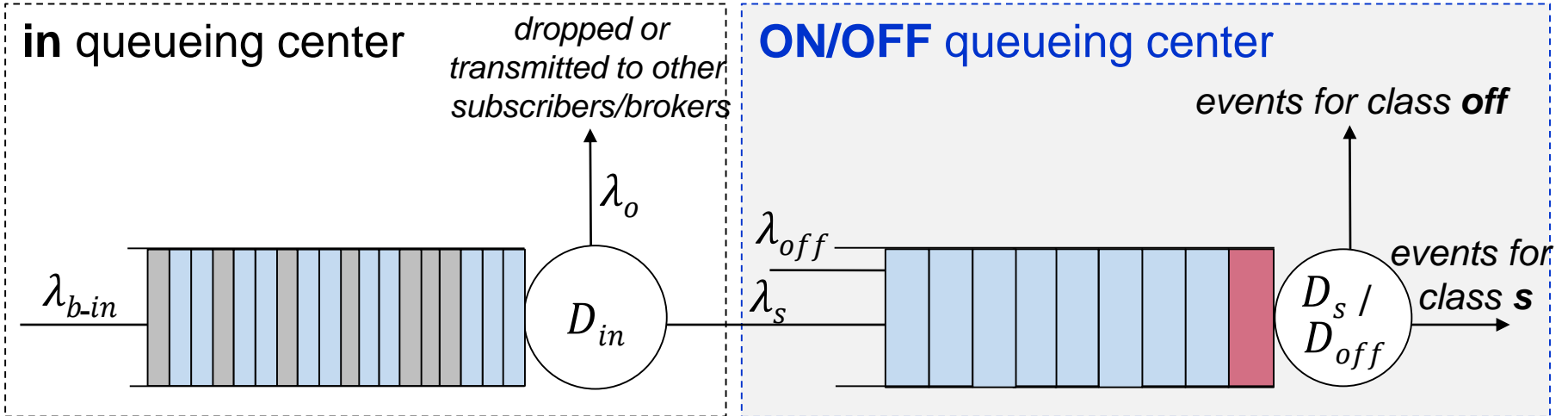
- 2-class queueing center with 'off' and 'normal' events
- model T_{OFF} intervals as arrivals of 'off' events
- 'off' events have preemptive priority over normal events



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

Home Broker Delay Calculation

broker node



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

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_{eff}^k at each queueing center.

Connect the publisher's queueing center::

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

$\lambda_0 \leftarrow \lambda_{ps}$, $D_{eff}^0 \leftarrow D_{eff}^{ps}(\lambda_{oth}^p, D^p)$;

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

if $k = K$ **then**

 Connect the queueing centers of s 's home broker:

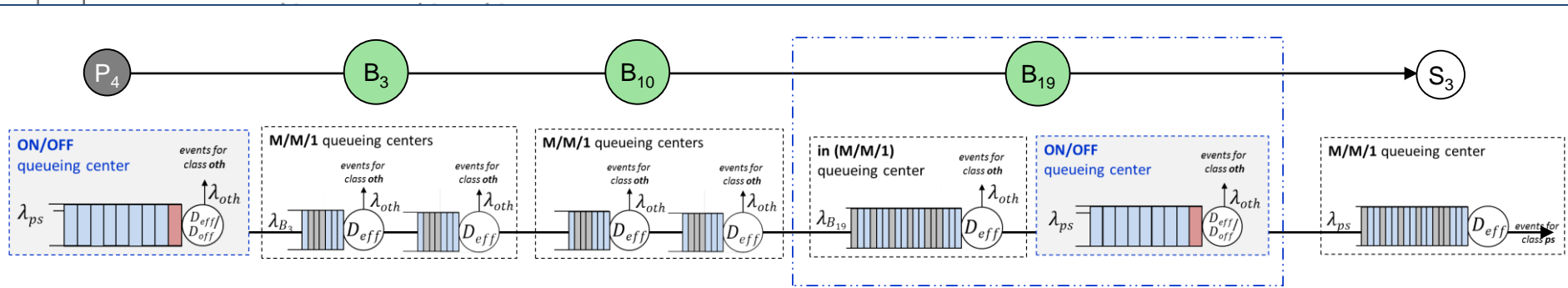
$QN \leftarrow QN + q_{m/m/1} + q_{on/off}$;

 M/M/1 queueing center;

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

 ON/OFF queueing center;

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



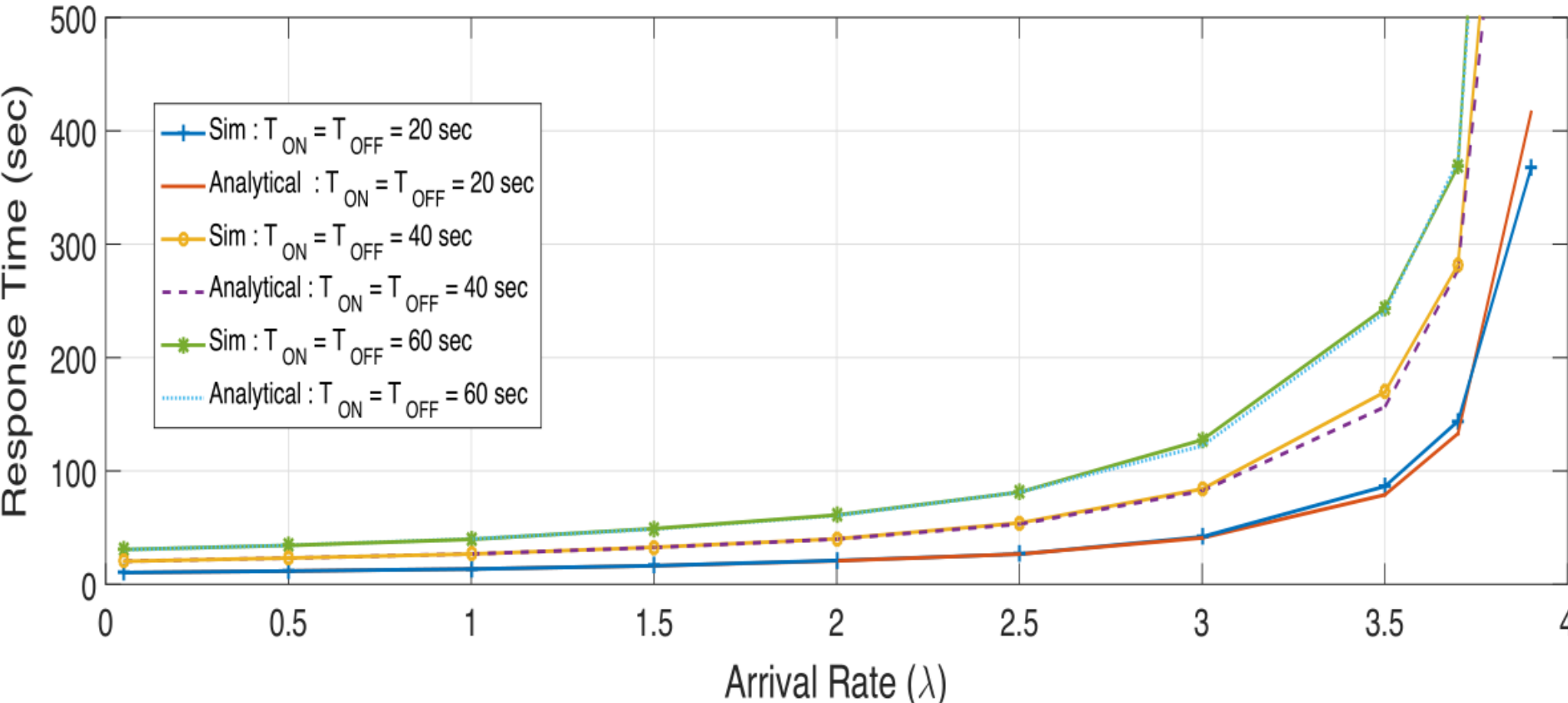
$\lambda_{k+1} \leftarrow \lambda_{ps}$, $D_{eff}^{k+1} \leftarrow D_{eff}^{ps}(\lambda_{oth}^{k+1}, D^{k+1})$;

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

Evaluation Results

- JINQS:
 - open source simulator for Queueing Network Models
- We extend JINQS and we have developed MobileJINQS¹:
- 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)

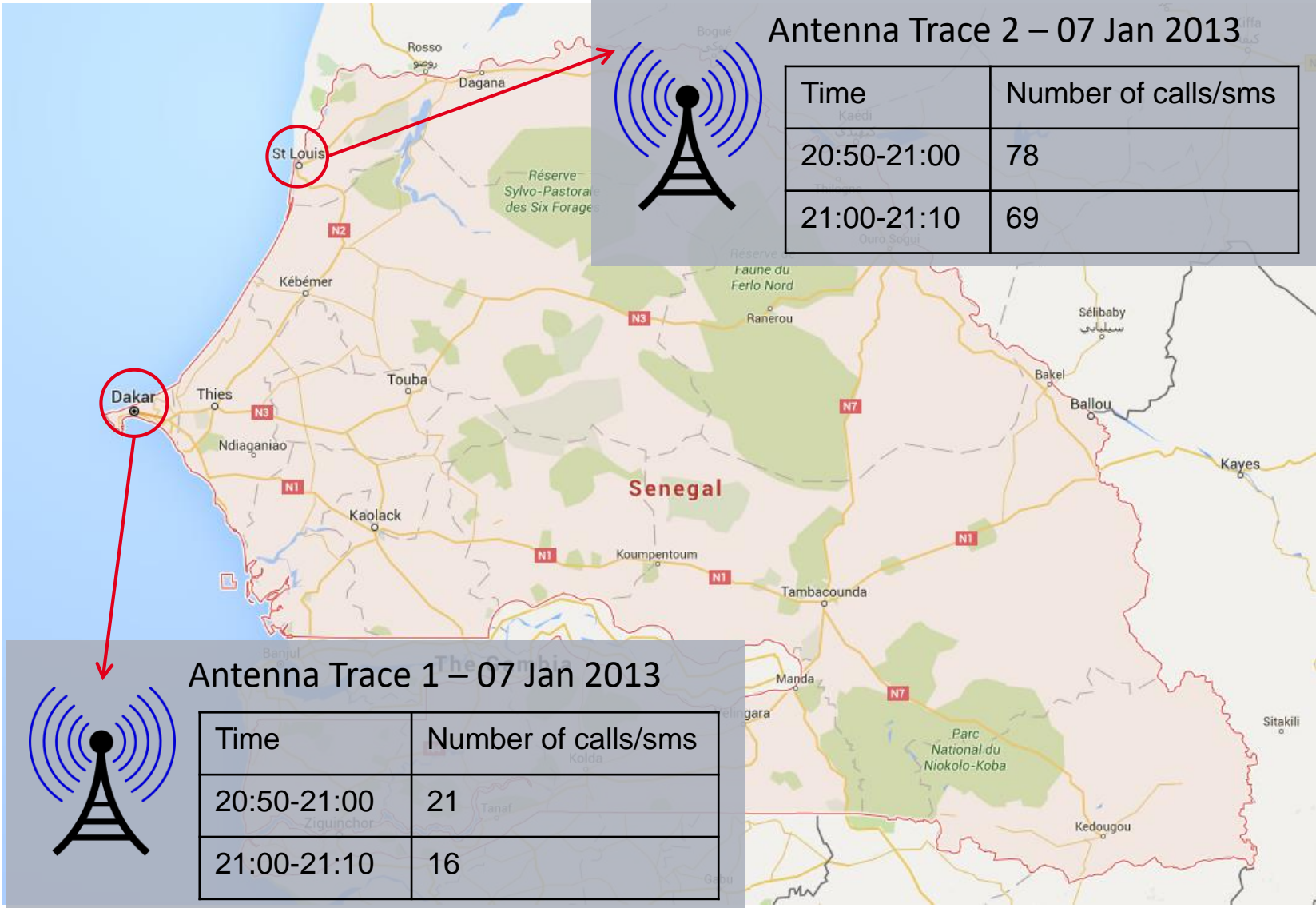
ON/OFF queueing center validation: Estimated vs. Simulated Response Time



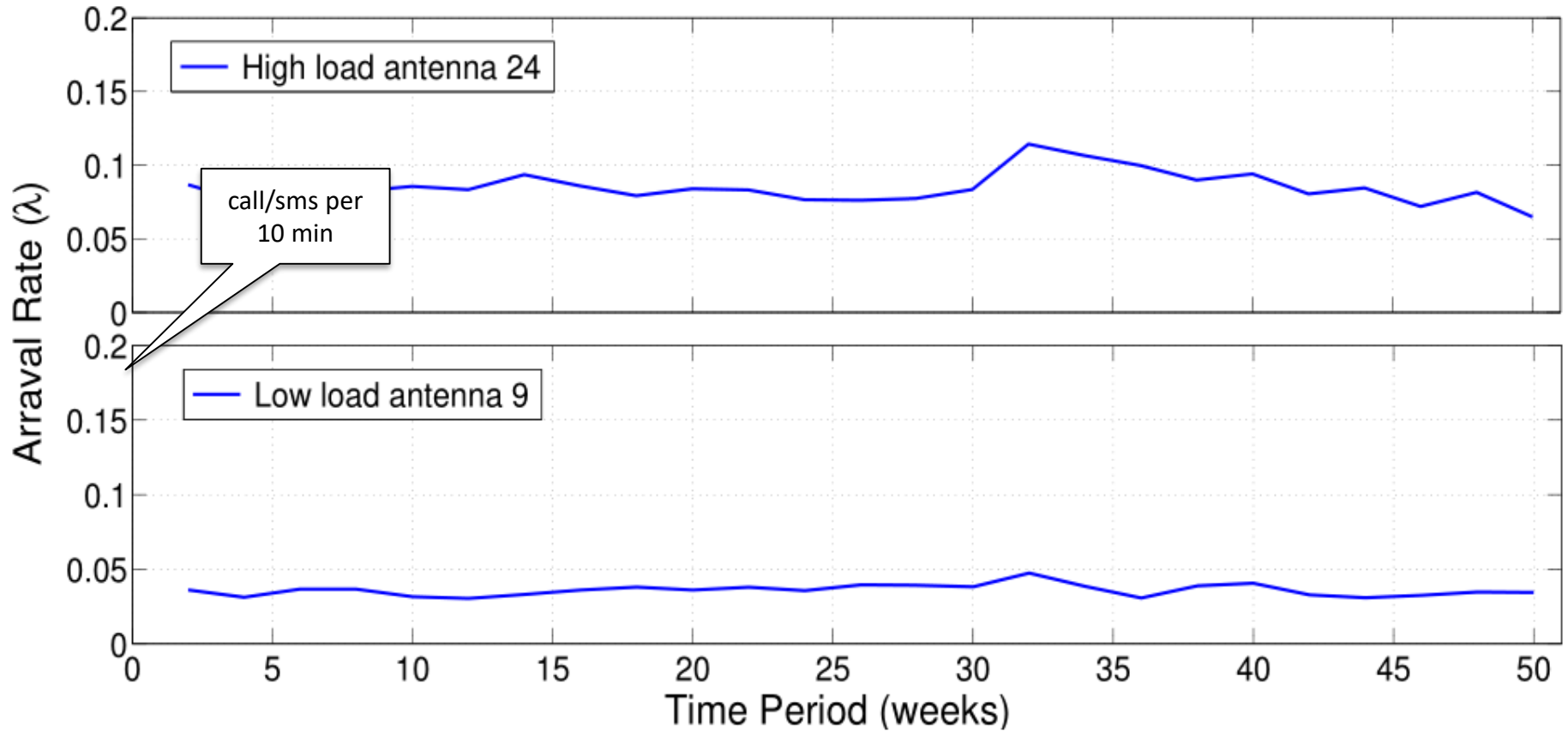


- D4D Dataset:
 - Generated by Orange labs for the subscribers of Sonatel Network in **Senegal**
 - Contains Call Detail Records (CDRs)
 - Collected over 50 weeks starting from 7th January 2013
 - For every 10 min interval at each antenna, they provide us the number of calls/sms
- CDRs for parameterizing our model¹ 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

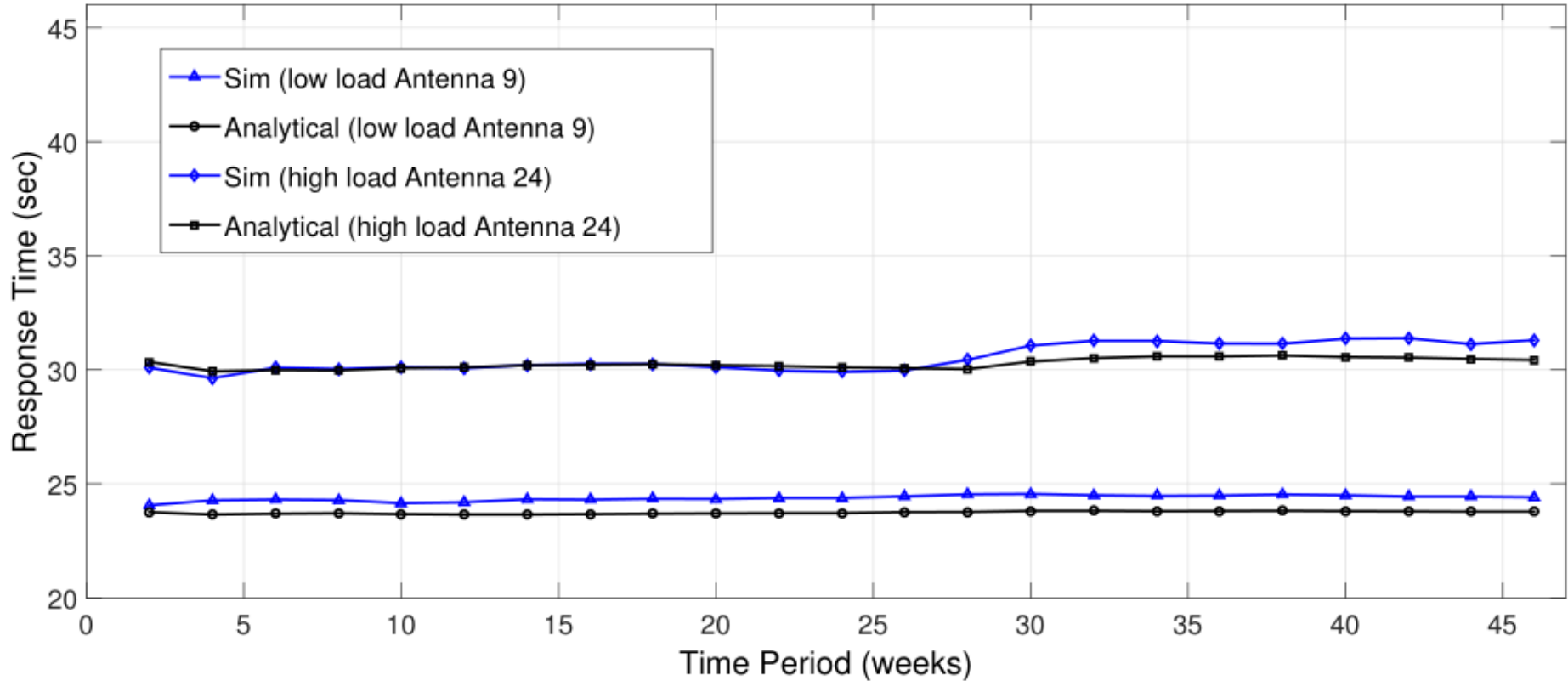
Antenna Real Traces



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

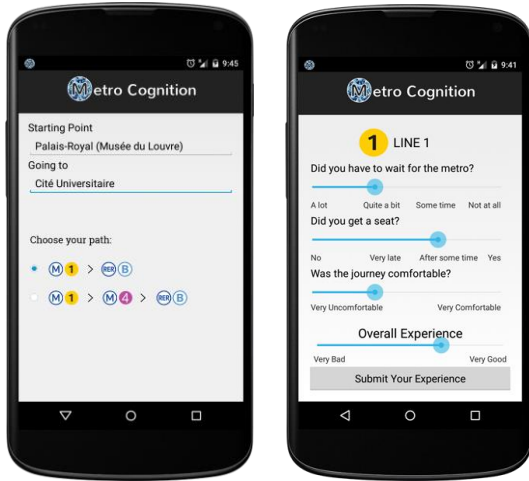


ON/OFF Queueing center Validation using Antenna traces (2)



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

Sarathi dataset: Metro Cognition¹ Android Application



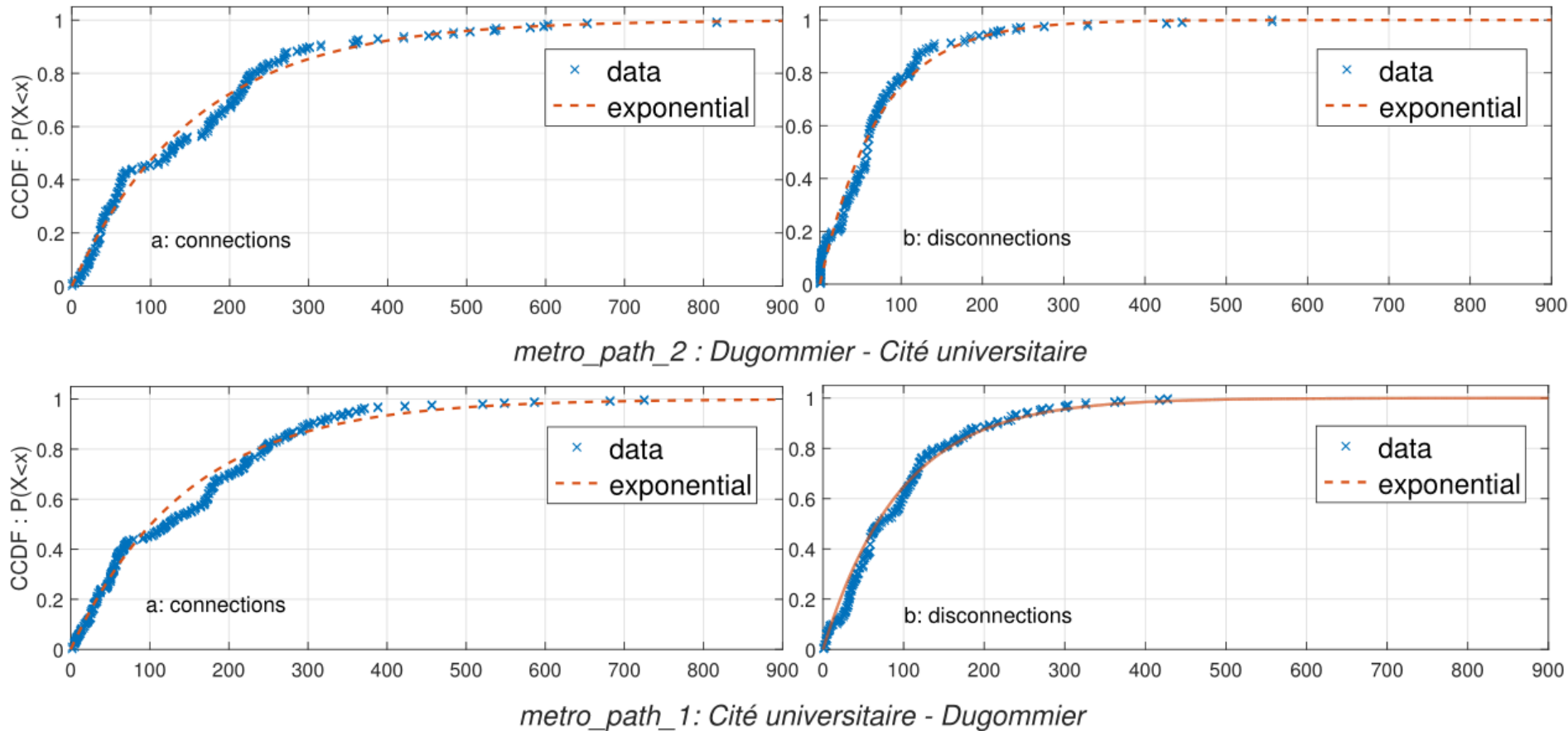
- collects connectivity tuples (*con_tuple*) every 30 seconds using a background service
- each *con_tuple* represents the Internet connectivity status (ON/OFF)
- one connectivity pattern (*con_pattern*) consists of many *con_tuple* in one specific path
- the *GoFlow*² pub/sub middleware is used for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

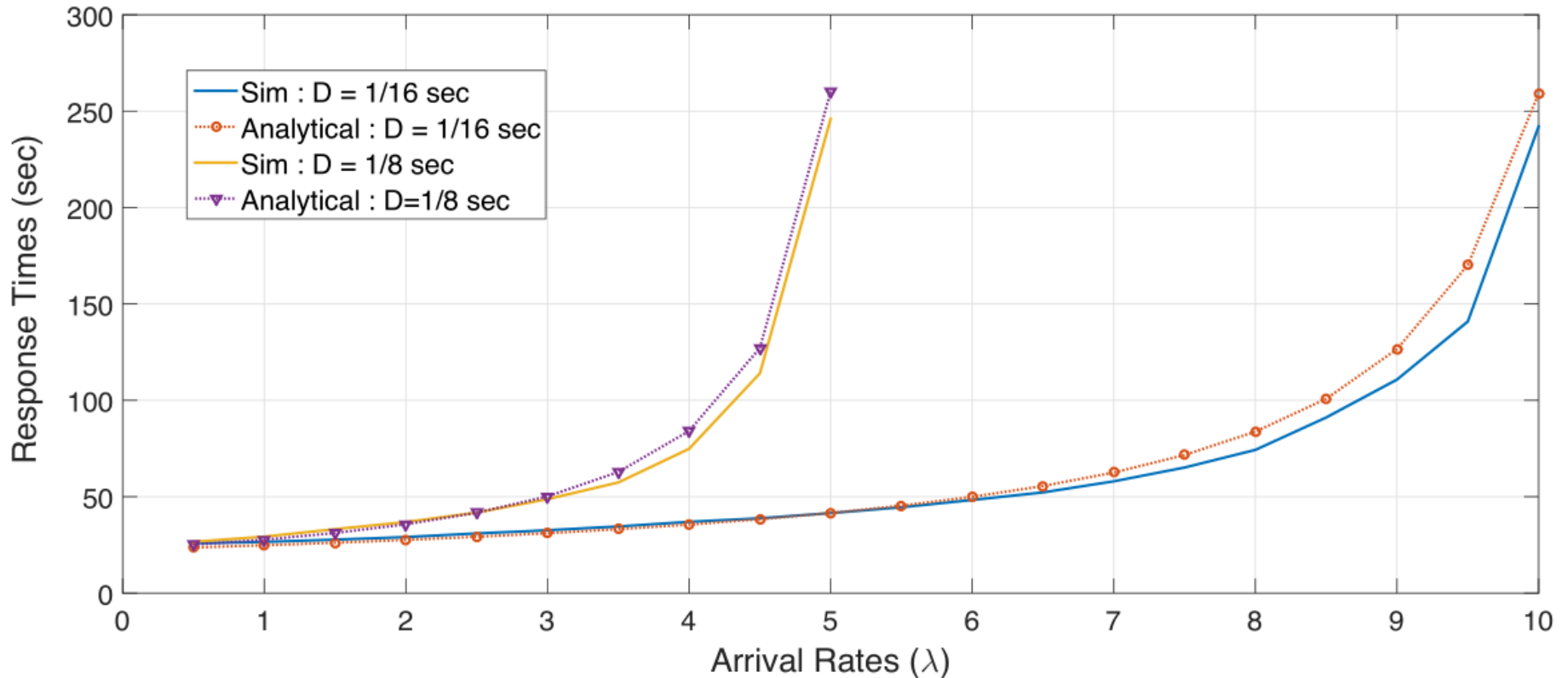


ON/OFF QS Validation using Connectivity traces (1)



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* \rightarrow *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 travels: *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

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

