Scandinavian Workshop on
Test-bed Based Wireless Research

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Toward a Development of LTE for Smart Energy Systems

KTH Royal Institute of Technology,
Stockholm, November 27-th, 2013

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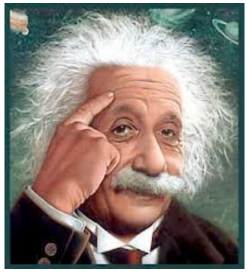
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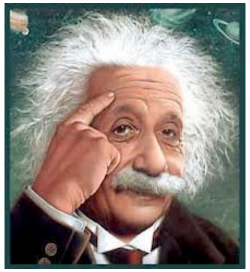
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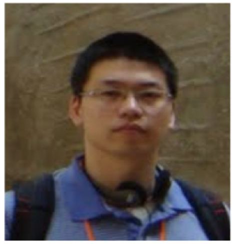
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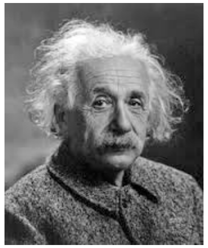
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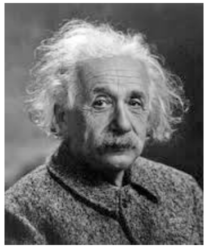
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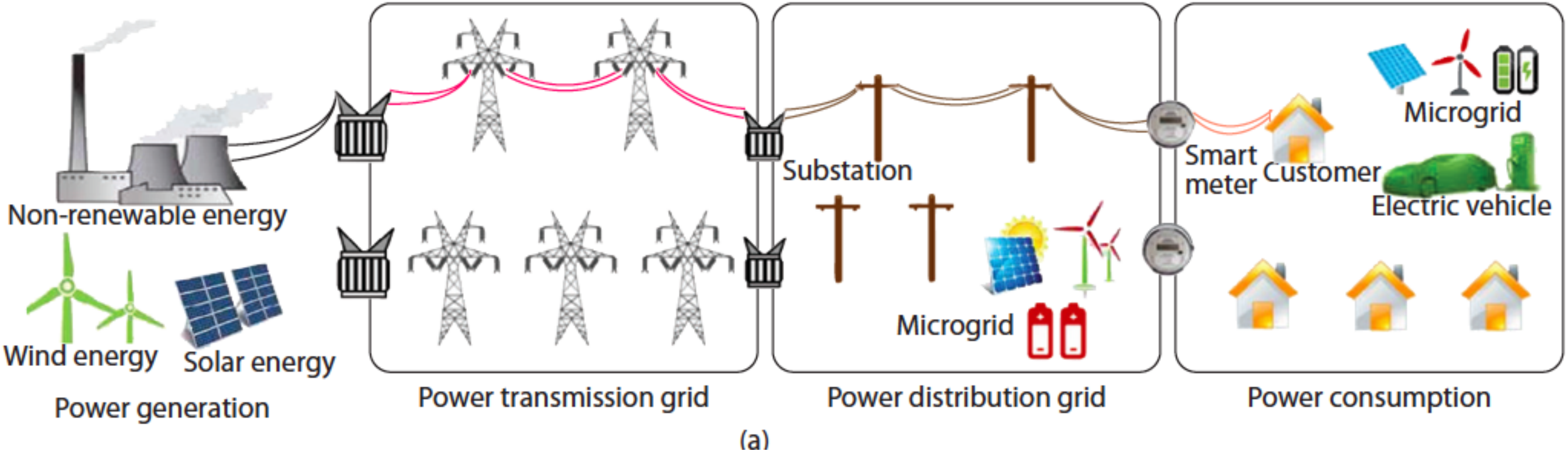
- Fast Distributed Optimization
- Privacy Preserving Distributed Optimization
- Millimeter Waves Wireless Networks
- Wireless Sensor Networks
- Networked Control Systems
- Cognitive Radio Networks
- ICT for Smart Grids

Outline

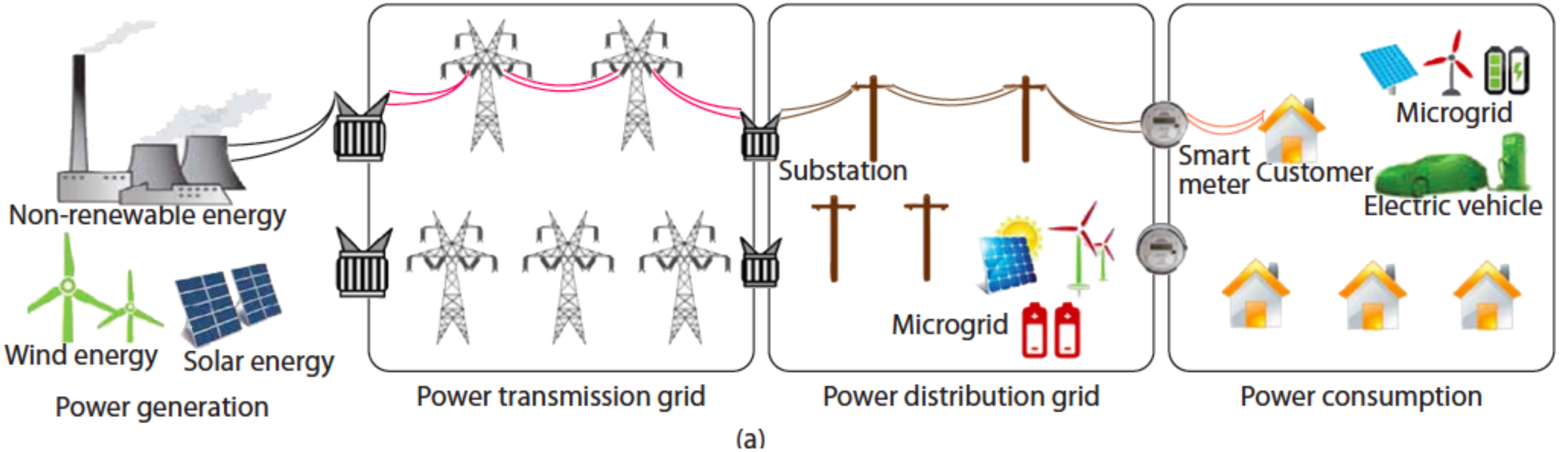
- **Smart Grids overview**
- Research aims
- Experiments from test-bed implementation
- LTE enhancement
- Conclusions

A Smart Grid



Ho et al., “Challenges and Research Opportunities in Wireless Communication Networks for Smart Grids”, IEEE Comm. Mag. 13

Communication sources in smart grids

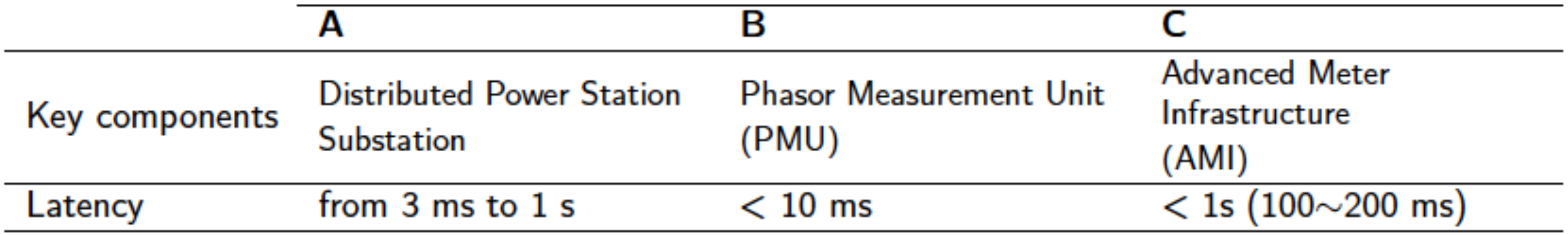


The communication in a smart grid consists of three key components

A. Distributed power station substation
B. Remote sensing devices, e.g., Phasor Measurement Unit (PMU)
C. Household devices, e.g., Advanced Metering Infrastructure (AMI)

Latency requirements

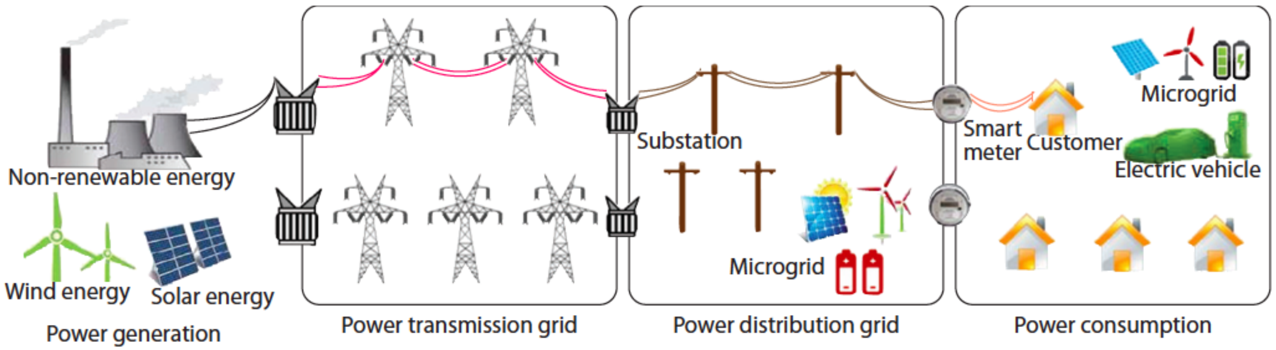
- Latency requirements for real time control of the smart grids from the key components



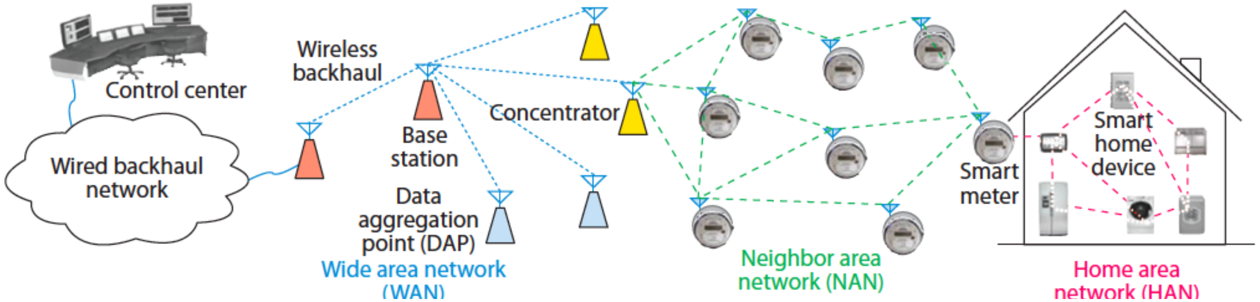
	A	B	C
Key components	Distributed Power Station Substation	Phasor Measurement Unit (PMU)	Advanced Meter Infrastructure (AMI)
Latency	from 3 ms to 1 s	< 10 ms	< 1s (100~200 ms)

- Summary:
  - Latency required < 10 ms for real time control from PMUs and AMIs.
  - Which technology using for the communication?

Candidate communication protocols



(a)



	LTE-Advanced	3G (HSPA+)	PLC	802.22
Latency (msec)	<5	<50	<10	<20
Data rate DL/UL (Mbps)	1000/500	28/11	3/3	18/18
Range (km)	100	10	5	100
Main Limitation	-	Very limited number of supported connections	Additional hardware equipment (couplers) needed at transformers	No QoS guarantees due to faulty spectrum sensing

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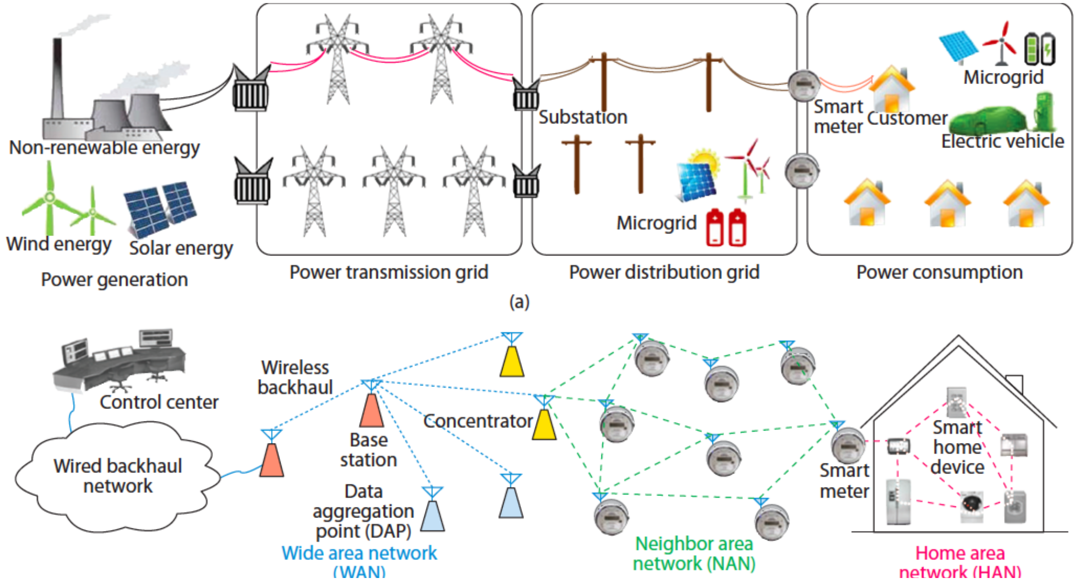
Research aims

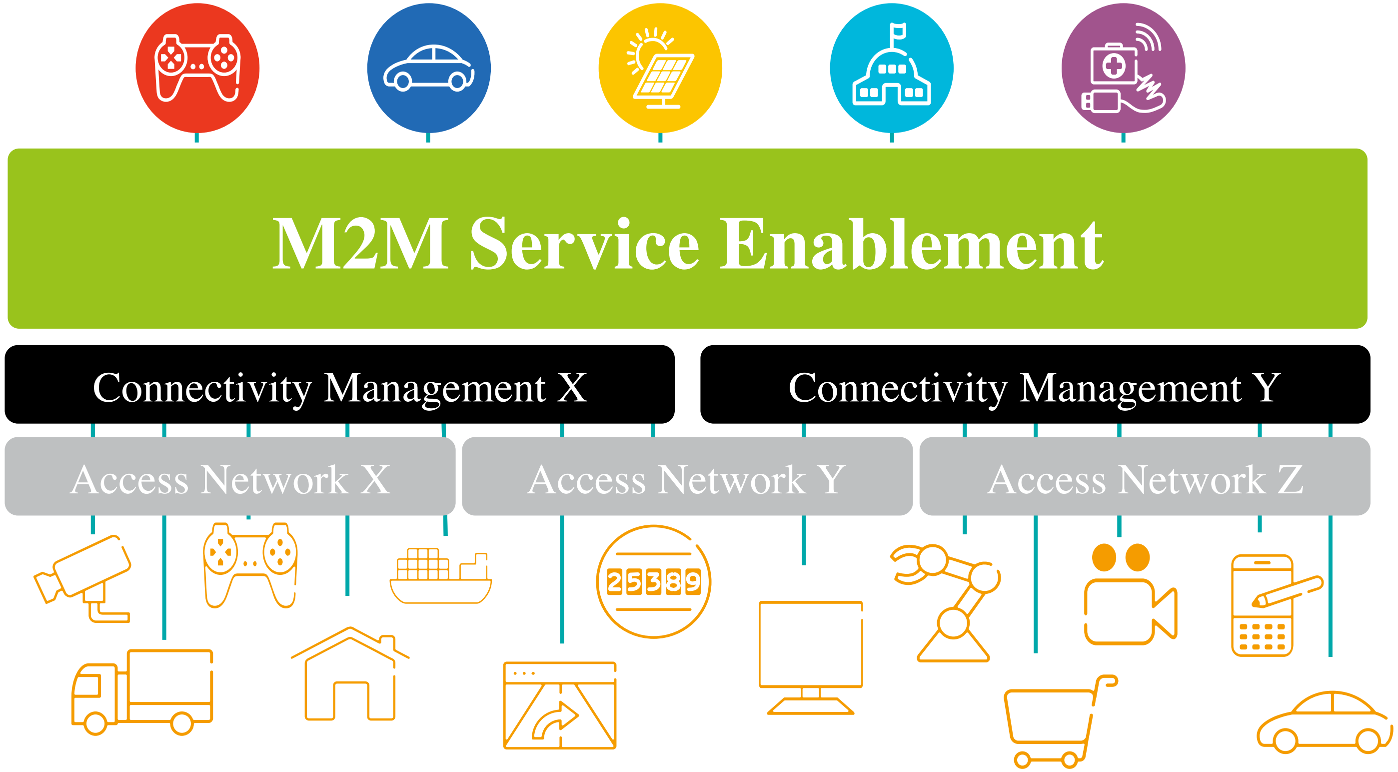


- Smart grid needs adaptive communication infrastructure for both short and long range remote real-time control

- Long Term Evolution (LTE) is a potential solution

  - Does LTE offer low latency for real-time control of the smart grid?
  - For which cases LTE is suitable?

LTE – M2M Service Enablement



Smart-grid Service Enablement Platform enables the integration of Smart grids services and LTE

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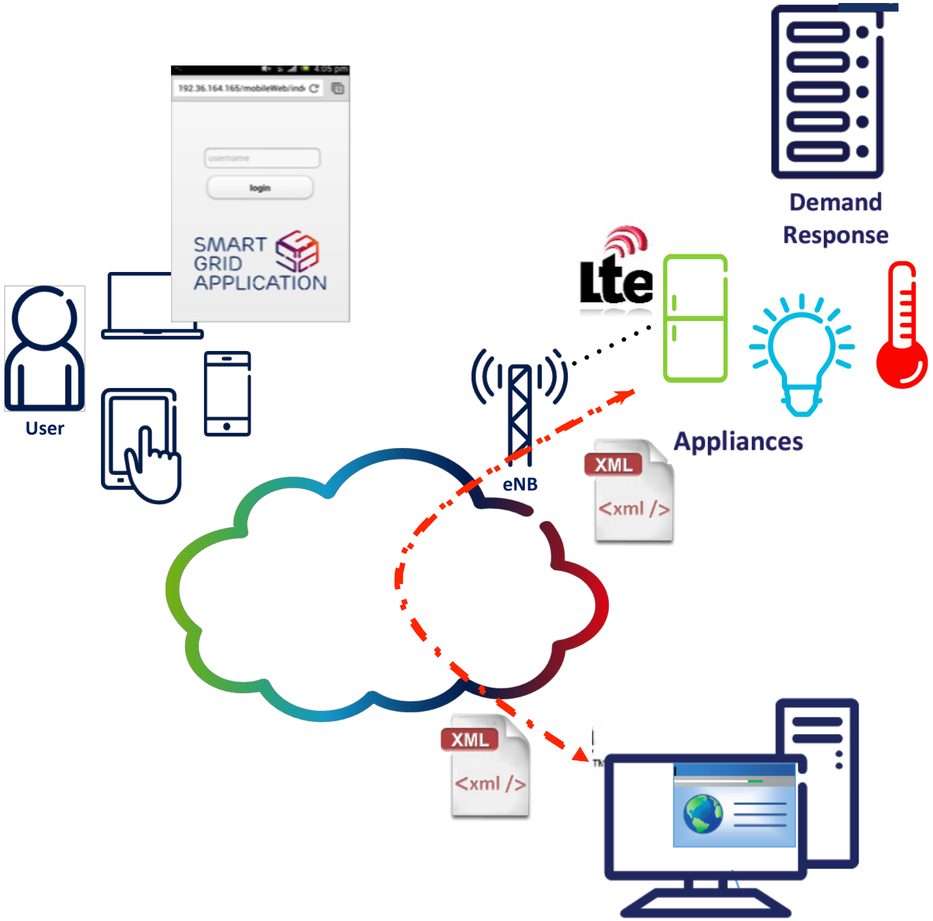
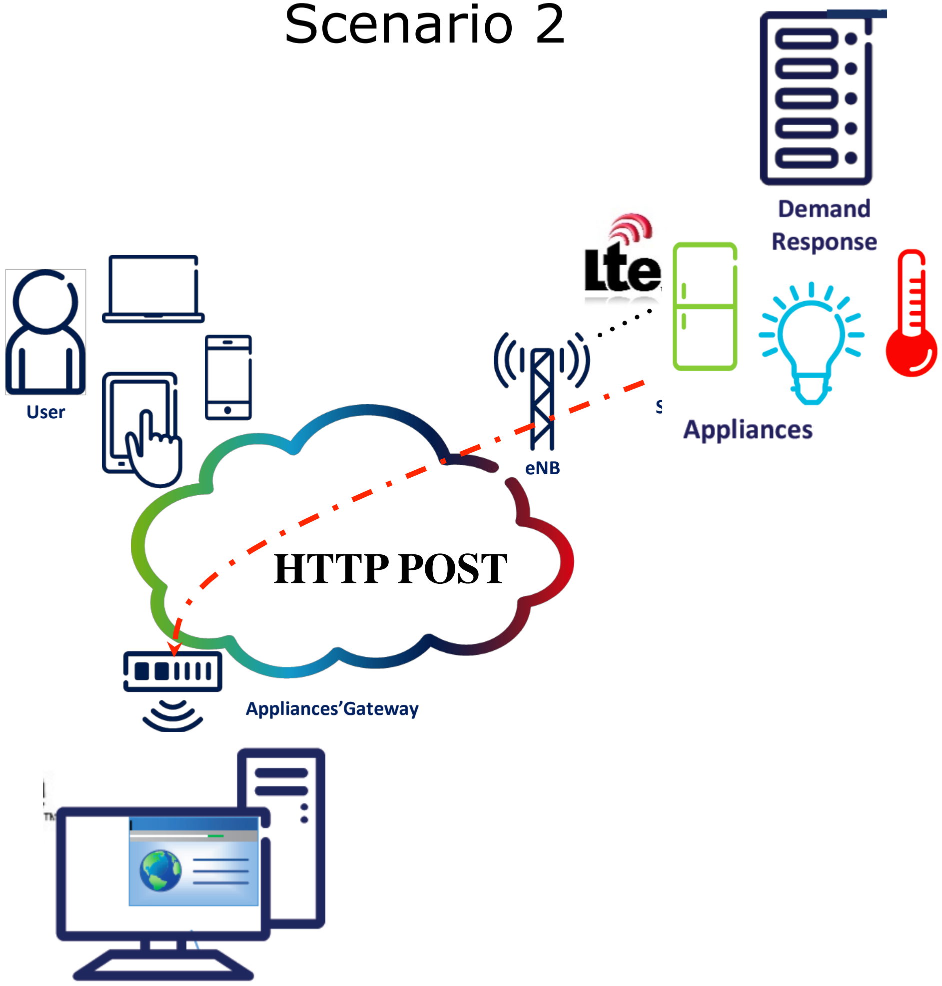
Test-bed

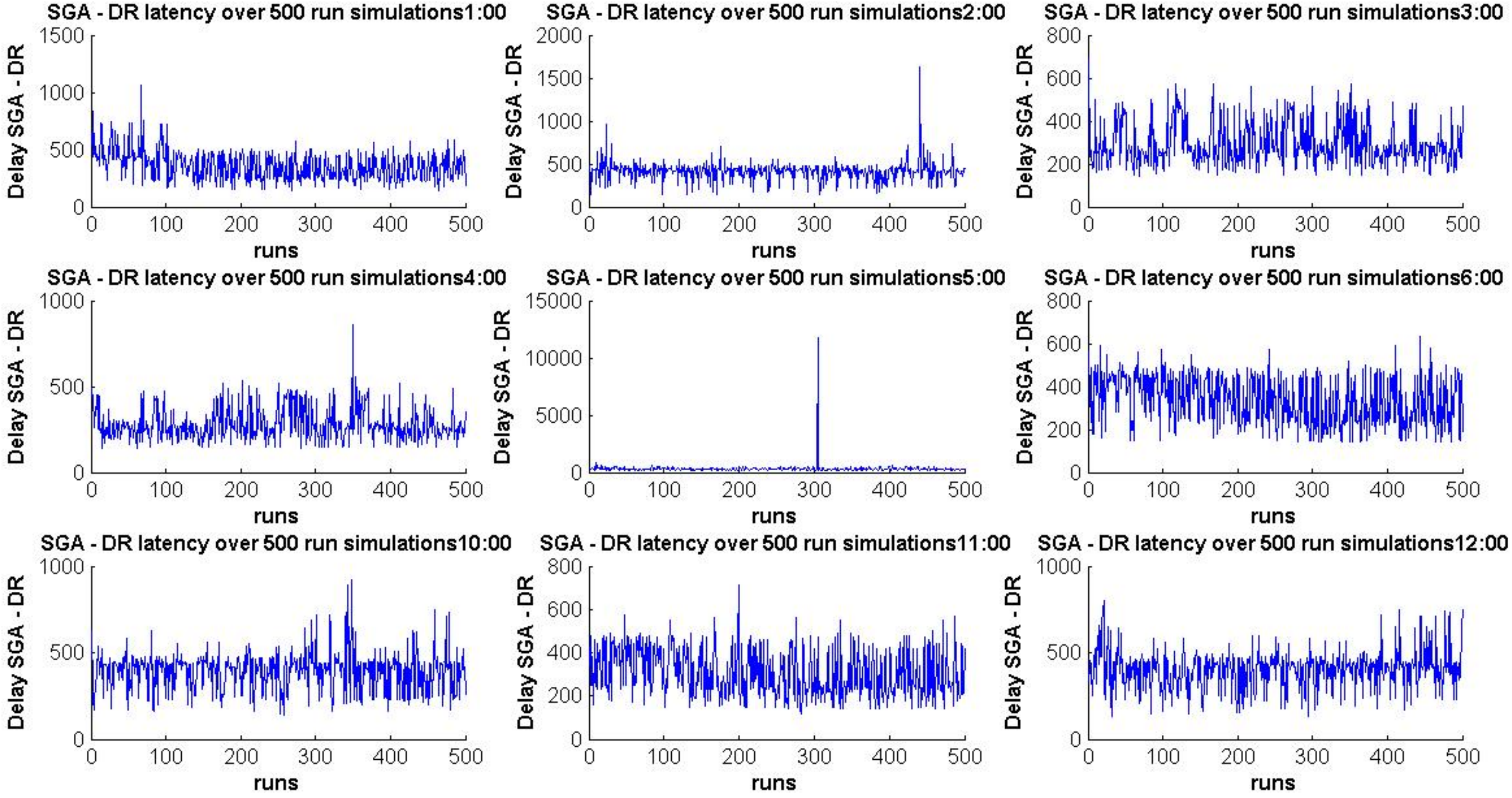
Scenario 1



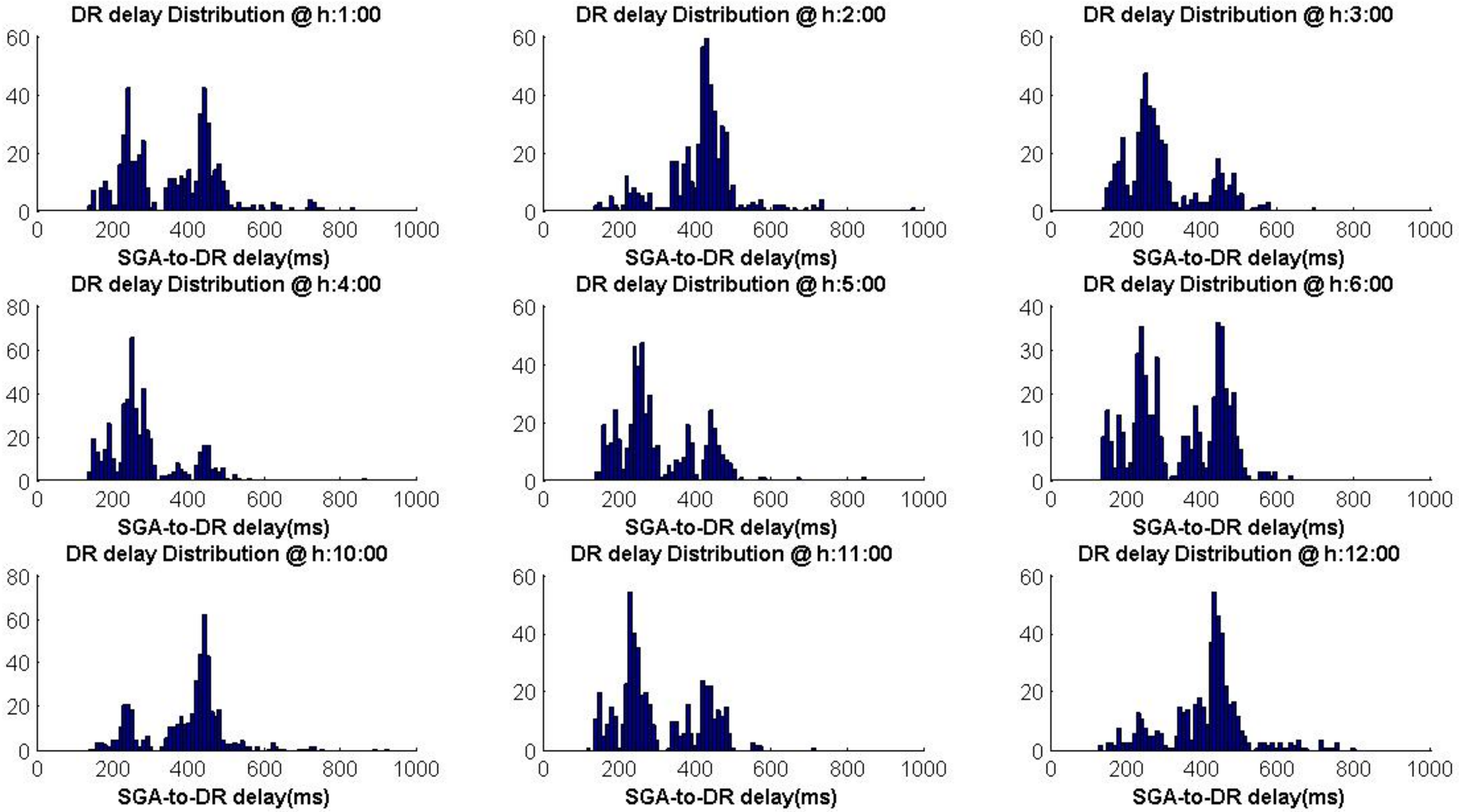
Scenario 2



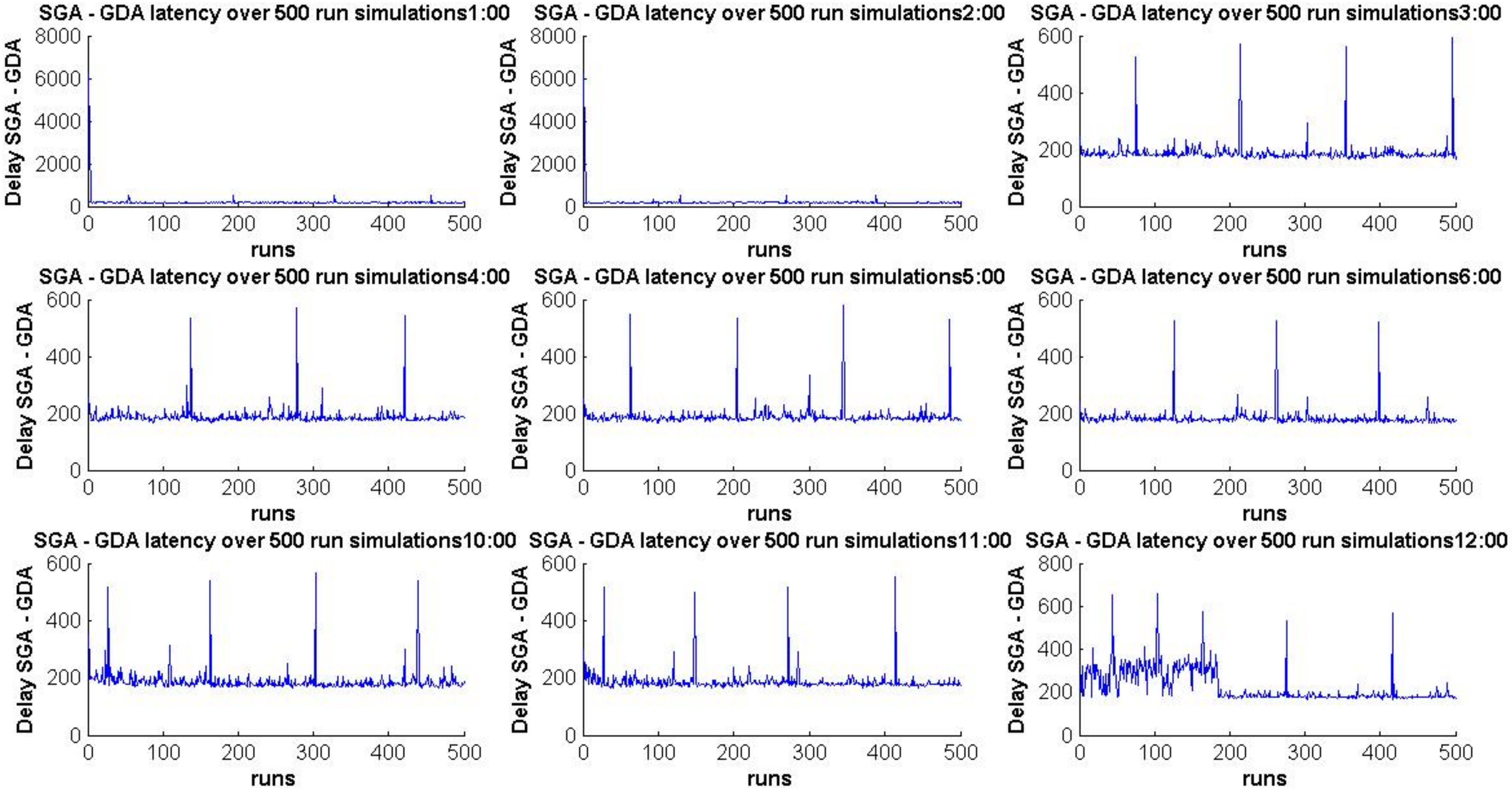
Scenario 1: end-to-end delay during day time



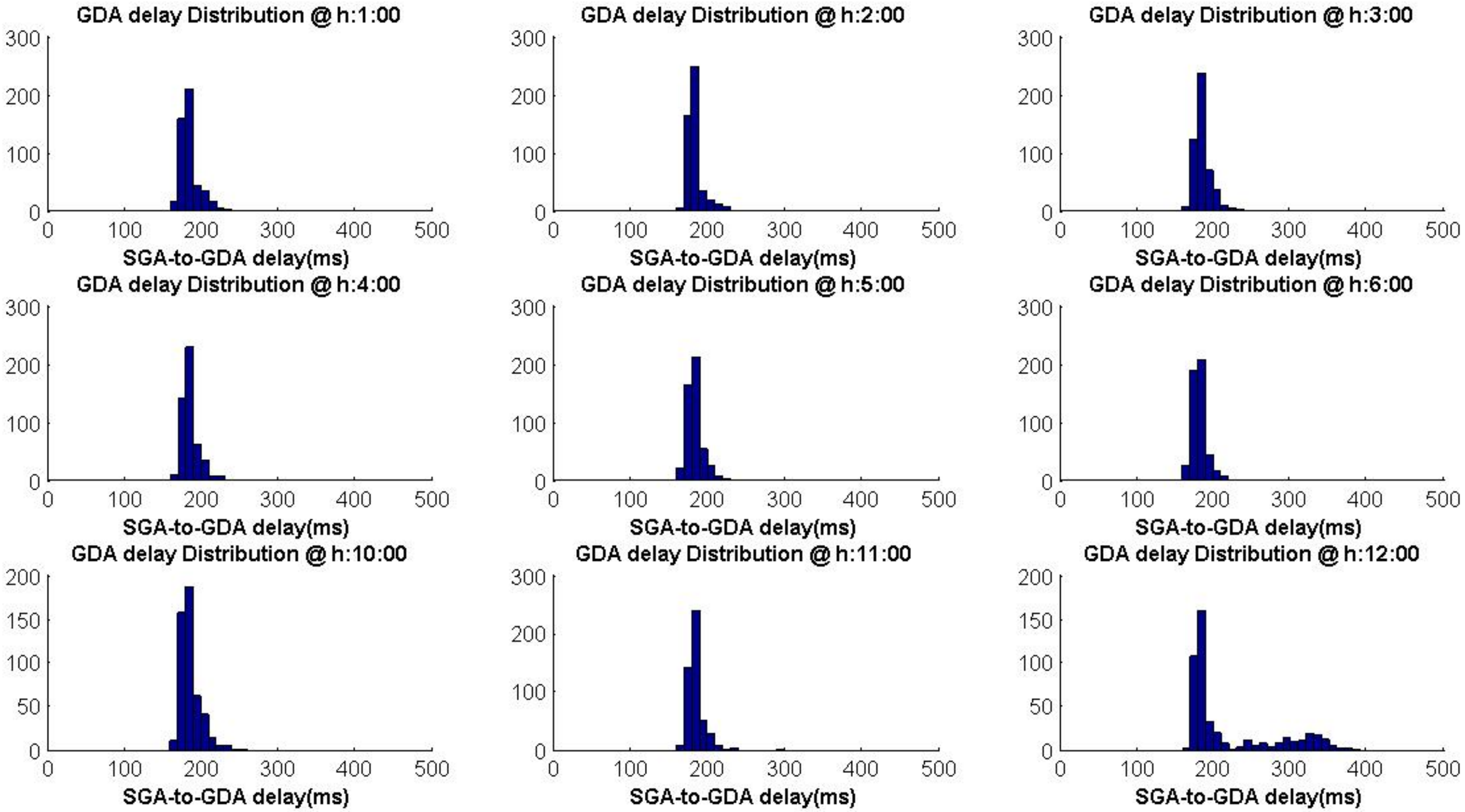
Scenario 1: end-to-end delay distribution during day time



Scenario 2: end-to-end delay during day time



Scenario 2: end-to-end delay during day time



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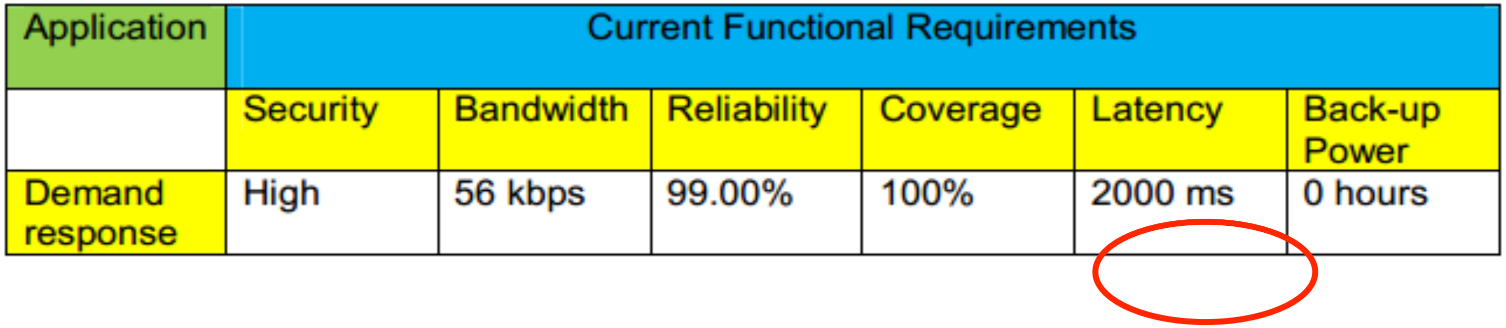
Summary: Average Latency

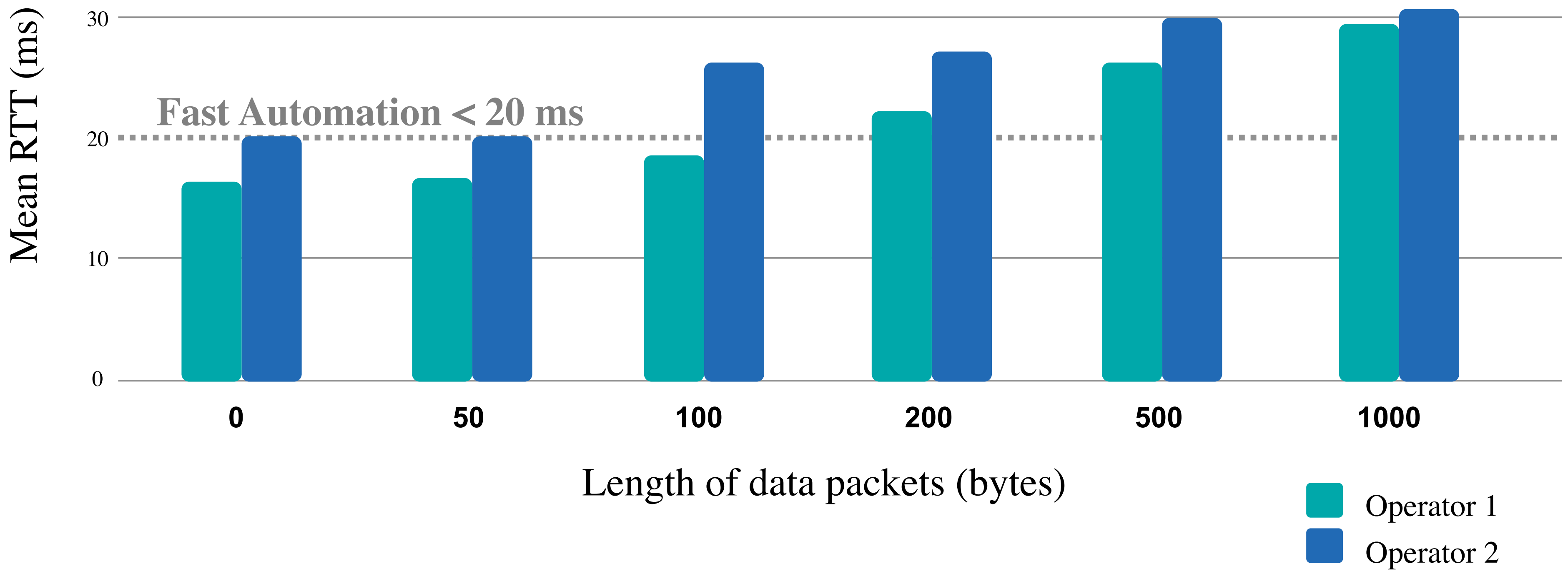
	Latency
Network and buffering delay	~ 20 - 25 ms
Communication delay	~ 100 ms
Processing delay	few µs
Computation delay	100 ms – 1 sec

- Most Smart Grid applications have strict latency requirements in the range of 100 milliseconds to 5 seconds
- Demand Response Applications



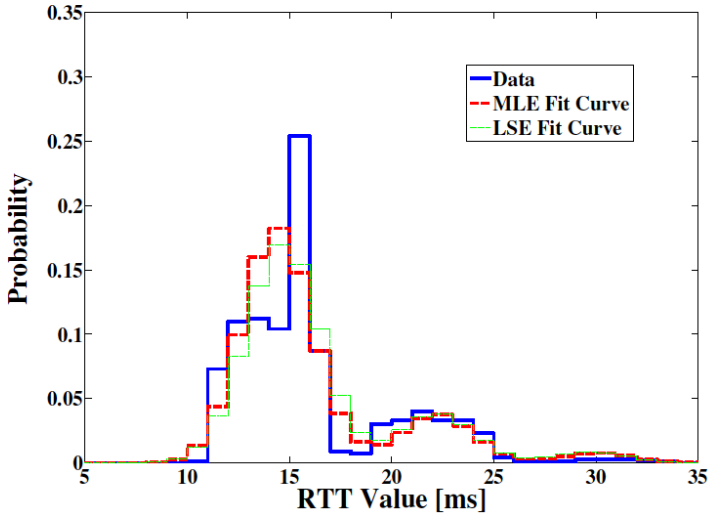
Application	Current Functional Requirements					
	Security	Bandwidth	Reliability	Coverage	Latency	Back-up Power
Demand response	High	56 kbps	99.00%	100%	2000 ms	0 hours

Summary: LTE Interface Average Latency

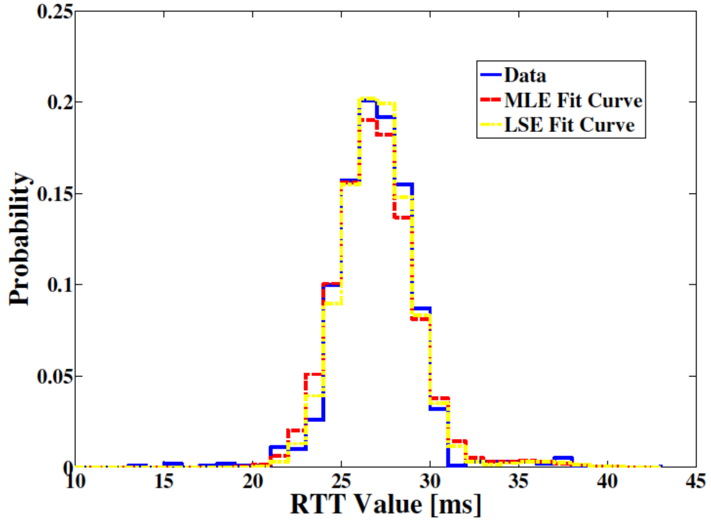


- LTE latency in terms of round-trip times (RTTs) for different packet sizes.
- LTE might not accommodate Smart Grids applications with tight latency requirements

Empirical latency distribution



(a) Via Operator 1 LTE network



(b) Via Operator 2 LTE network

- An empirical latency distribution model is

$$f(x)=\sum_{i=0}^{H}\sum_{j=0}^{H}(1-p_{\mathrm{up}})(1-p_{\mathrm{down}})p_{\mathrm{up}}^{i-1}p_{\mathrm{down}}^{j-1}N(\mu-iT_{\mathrm{up}}-jT_{\mathrm{down}},\sqrt{\sigma_{\mathrm{up}}^2+\sigma_{\mathrm{down}}^2})$$

- where
  - p is the probability of repeating request,
  - T is the time spent on resending
  - subscript up, down represent up- and down-link respectively.

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LTE Interface Latency

- LTE latency can be improved by a adaptive scheduler

- Goal:
  - Optimal usages of the LTE physical resources
  - Lower latencies for Devices used in Smart Grids

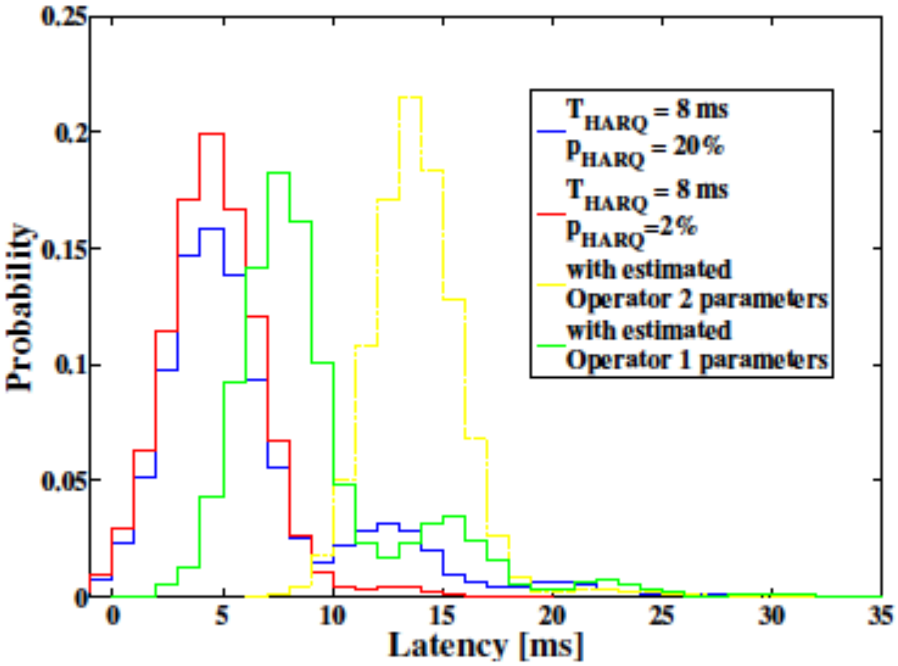
- Strategy:
  - Scheduler as an optimization problem making an optimal usage of LTE in time- and frequency-domain for smart grid components
  - Design the utility giving higher priority to the Devices in Smart Grids

LTE Scheduler for Smart Grids

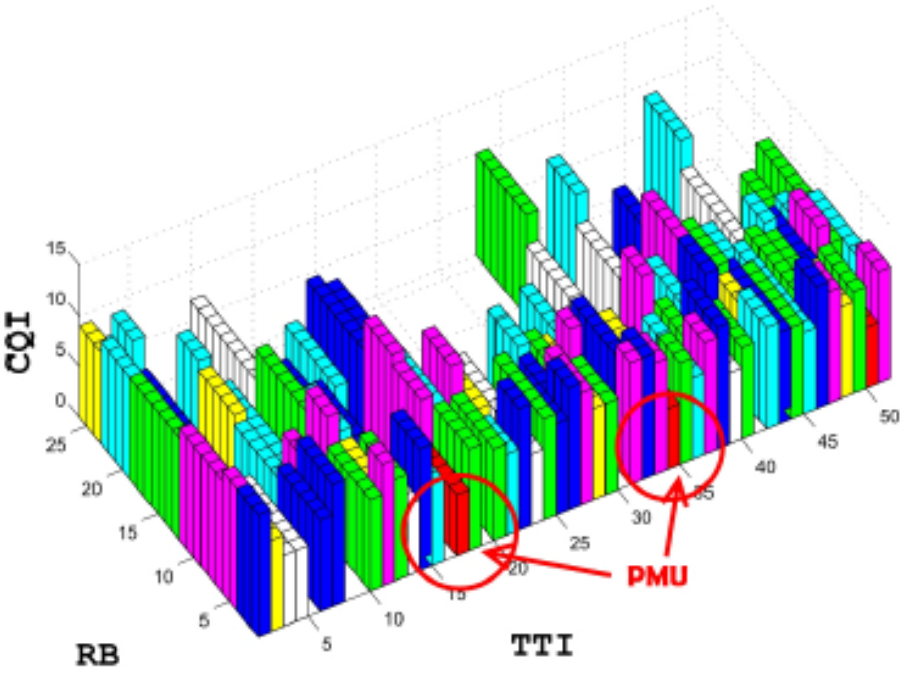
- The scheduler is designed as an optimization problem

$$
\begin{aligned}
\max_{i,j,c} \quad & \sum_{c=1}^{N} \sum_{i=1}^{N_{\mathrm{TTI}}} \sum_{j=1}^{N_{\mathrm{RB}}} R_{i,j}^{(c)} x_{i,j}^{(c)} & \\
\text{s.t.} \quad & \sum_{c} x_{i,j}^{(c)} \leq 1 \quad x_{i,j}^{(c)} \in \{0,1\} & \forall i,j \\
& \sum_{i} x_{i,j}^{(c)} \leq N_{\mathrm{TTI}} & \forall j,c \\
& \sum_{j} x_{i,j}^{(c)} \leq N_{\mathrm{RB}} & \forall i,c \\
& \sum_{i} \sum_{j} x_{i,j}^{(c)} \leq L^{(c)} & \forall c\,,
\end{aligned}
$$

Simulation results



(a) Latency distribution offered by the new LTE scheduler



(b) Allocation procedure illustration

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Conclusions

- Presented an initial test-bed for LTE in Smart Grids
- Measured the latencies to connect Smart Grids objects
  - LTE and network connections give good latencies for Demand Response applications
- Proposed an LTE scheduler for Smart Grids
- To do: A through investigation of which Smart Grids applications benefit from LTE

Acknowledgement

- George Athanasiou
- Michele Partemi
- Yuzhe Xu

- This work was performed within the EIT ICT Labs, Wireless@KTH, and Ericsson-ACCESS projects on LTE for Smart Energy Systems