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School of Computing Science

Essence: Pervasive & Distributed Computing

QUALITY-AWARE PREDICTIVE MODELLING & INFERENTIAL ANALYTICS AT THE NETWORK EDGE

PhD Thesis – Viva – 25.08.2021

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WORLD CHANGING GLASGOW

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Motivation

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	Adaptation	Bandwidth	Computation	Connectivity	Energy	Real-Time	Privacy	Storage
Cloud	✗	✗	✓	✗	✓	✗	✗	✗
Edge	✓	✓	✗	✗	✗	✓	✓	✗

✓ Feature ✗ Limitation

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Why Quality-Aware?

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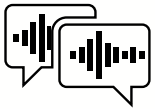
Use Cases

Autonomous Car

Health

Smart Home



Speech Recognition

Poor Quality Consequences

- Wrong Decision Making
- Costly Mistakes
- Harmful Outcome
- Decrease User Satisfaction
- Horrible Customer Experience
- Incorrect Conclusions

It is essential to have high quality analytical results.

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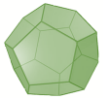
Contributions



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Communication-Efficient Data Forwarding	Latency-Efficient Local Analytics	Privacy-Efficient Local Learning
• Reducing the frequency of data transmission by: – Prediction-based forwarding – Time-Optimised delaying • Reconstruction of missing values (imputation)	• Familiarity-based retraining of Local ML Model • Performance-based ML Model forwarding • Qualitative model selection for query analytics: – Quantisation Input/Error-Space – Similarity-based Clustering	• Enable *privacy by design* using Federated Learning • Combine generalisation and personalisation at the Edge • Qualitative local model selection: – Adaptive Weighting – Optimal Time of Switching

Hypothesis 1

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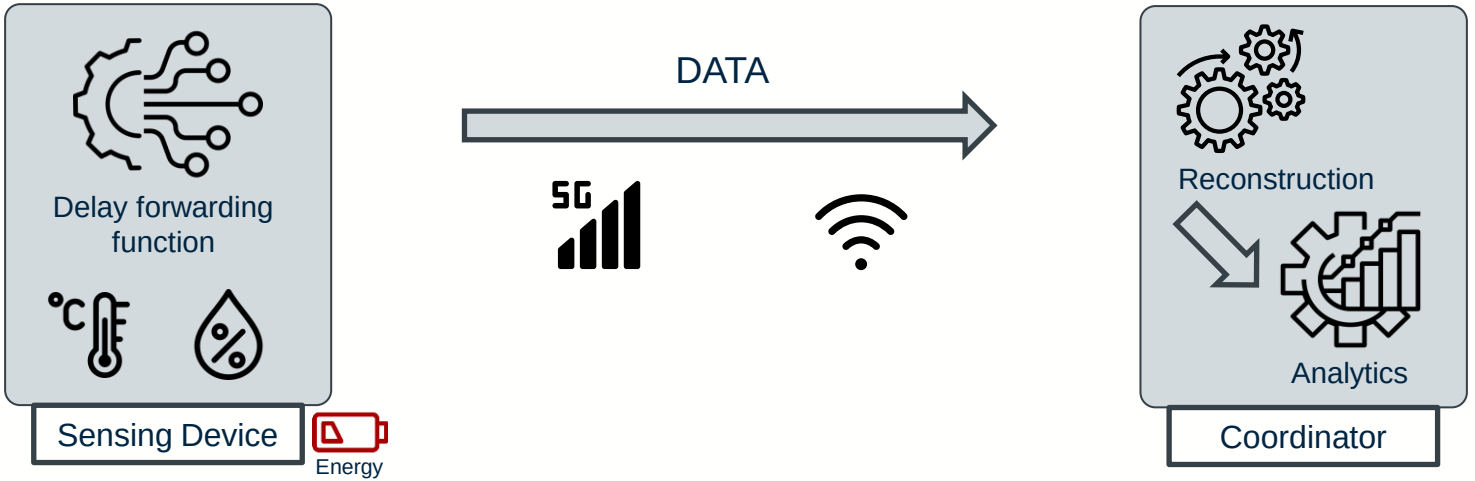
"Enabling computation at the Edge using efficient forwarding mechanism will reduce the communication, relieve the bandwidth and save energy at the device. Smart reconstruction functions at the central coordinator enable qualitative analytical results"

(1) Computational Intelligence

(2) Reduce Communication

(3) Quality-Aware Reconstruction



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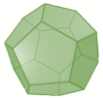
Quality-Efficient Data Forwarding



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Data Forwarding Mechanism

Prediction Based:
- SPD (Single Prediction Design)
- DPD (Dual Prediction Design)
- QEPD (Quality-Efficient Prediction Design)

Time-Optimised:
- TOFS (Time-Optimised Forwarding Strategy)
- HTOFS (Hybrid Time-Optimised Forwarding Strategy)

Reconstruction Policies

- NAIVE
- MEAN
- EWMA
- ARIMA
- LMS

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Performance Evaluation

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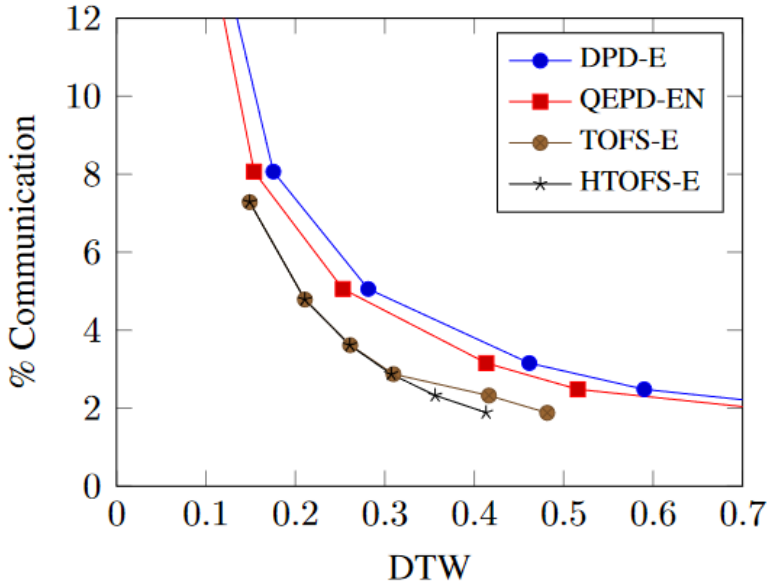
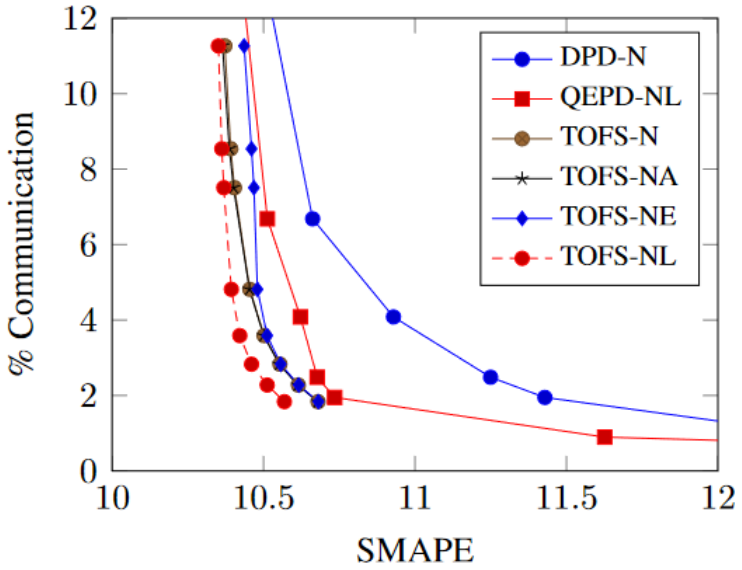
"Time-Optimised Data Forwarding Strategy reduces the communication while generating high quality results for analytical tasks"





Hypothesis 2

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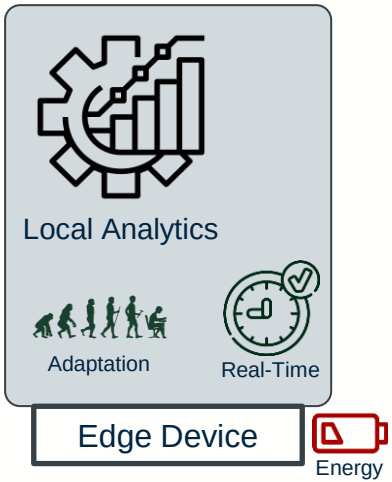
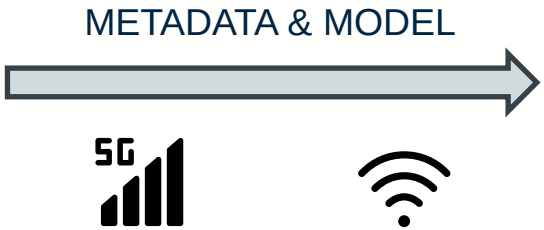
"Enabling analytics locally at edge devices will empower real-time applications that can adapt intelligently to concept drifts and changes of the continuous data arriving. These locally trained models can be selected through qualitative model selection methodologies at central coordinators"

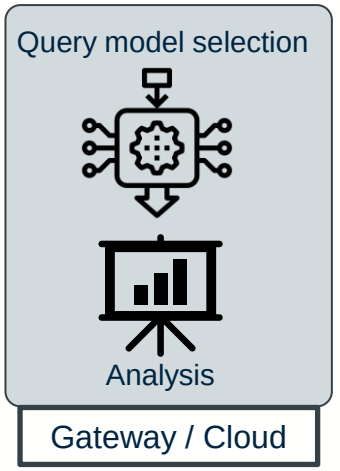
(1) Model Retraining

(2) Model Forwarding

(3) Qualitative Model Selection







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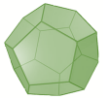
Latency-Efficient Edge-Centric Analytics



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Retraining of Model based on novelty of input

Quantisation of the input space and error as decision

Forwarding model based on

- Prediction Performance
- Model Fitting
- Parameter Divergence

Model Selection at the central coordinator

Based on the quantisation of the Input/Error-Space selecting Top-*K* models:

- IAM
- IEAM

Based on similarity-based clustering (SBSM)

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Performance Evaluation

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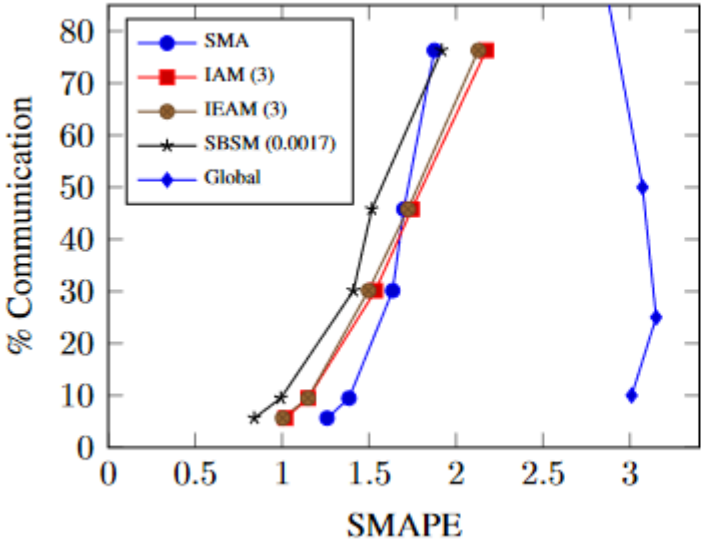
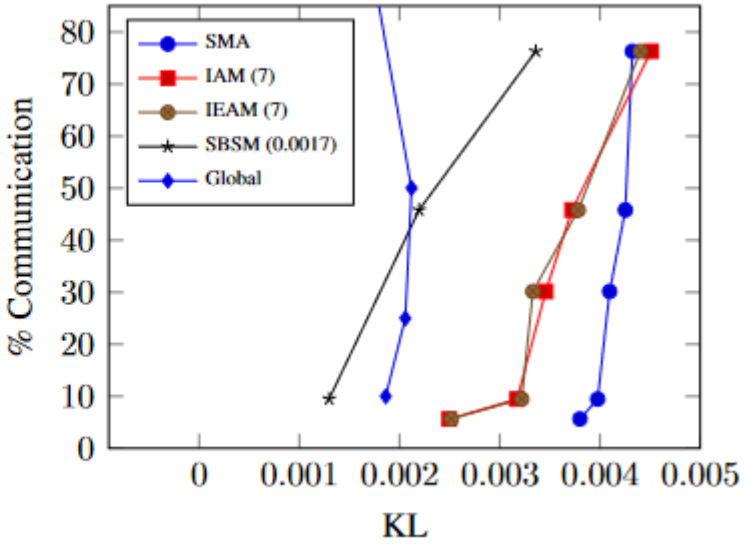
"Similarity-based model selection for queries is generating high qualitative results for analytical task while reducing the communication using the predictive performance forwarding methodology"





Hypothesis 3

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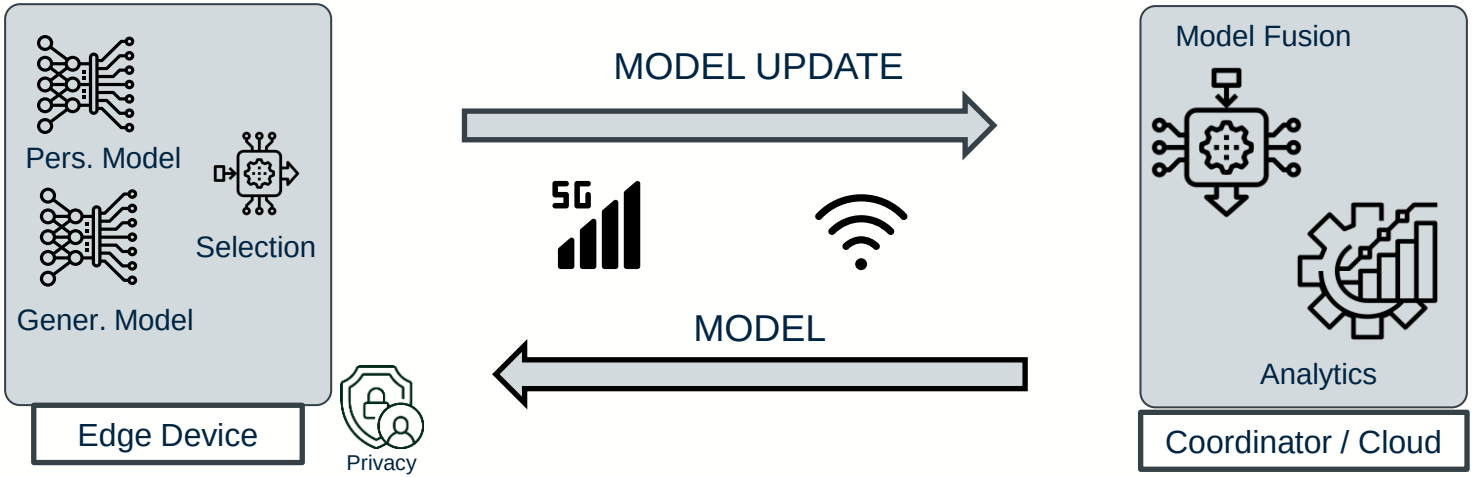
"Generalised models over privacy-preserved data will not provide qualitative results in constantly changing and heterogeneous environments. Local learned models and an intelligent model selection mechanism or weighting of personalisation and generalisation enables qualitative prediction results"

(1) Local personalised model

(2) Send generalised model

(3) Update generalised model

(4) Select best model for prediction



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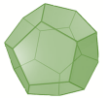
Privacy-Efficient Learning at the Edge



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Federated Learning to enable privacy-preserving of data by design

Continuously evolving and changing environments do not convergence, therefore personalisation and generalization is needed

What model is the best to use for a prediction locally:

- Adaptive Weighting of personal and generalised model
- Identifying the optimal time to switch the models

Performance Evaluation

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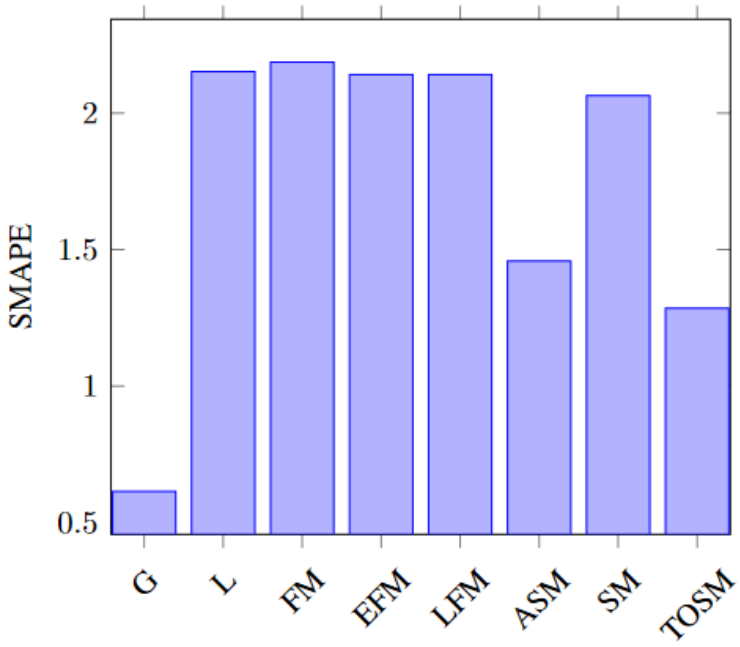
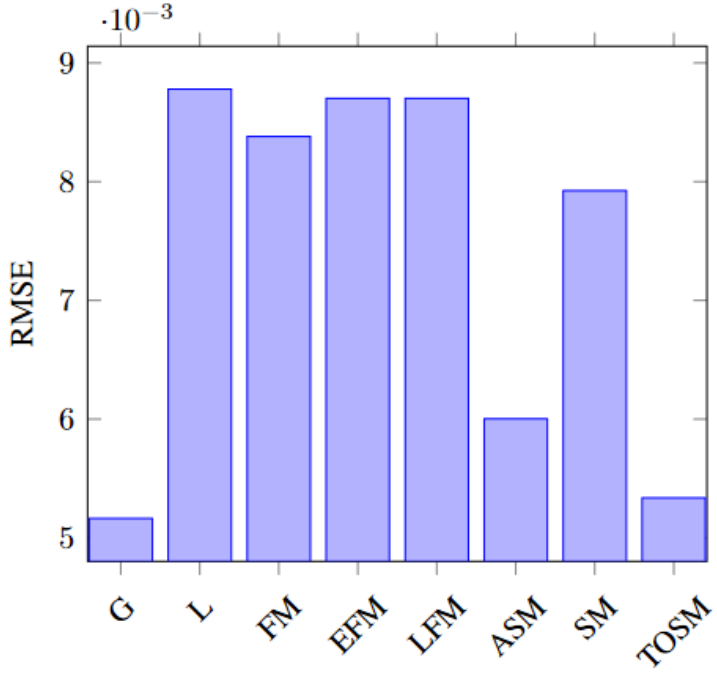
"Time-Optimised model selection and adaptive weighting of models is generating qualitative better results than the federated or local model"





Summary

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Applications able to handle raw-data while trying to increase lifetime of devices and reducing bandwidth.

TOFS

Applications important to perform local real-time decision making but the need of central query analysis.

SBSM

Applications important to enable privacy and decentralized learning over continuous evolving data.

ASM & TOSM

Next Steps

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PhD Thesis

Federated Learning:

- … over multiple hierarchies
- … with other security mechanism
- … on unsupervised learning tasks
- … using active learning

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Publications

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- Natascha Harth, and Christos Anagnostopoulos. ”Edge-centric efficient regression analytics.” *IEEE International Conference on Edge Computing* (EDGE 2018). San Francisco, CA, USA, July 2018, pp. 93-100
- Natascha Harth, and Christos Anagnostopoulos. ”Quality-aware aggregation & predictive analytics at the edge.” In: *IEEE International Conference on Big Data* (IEEE Big Data 2017). Boston, MA, USA, Dec.2017, pp. 17-26
- Natascha Harth, Christos Anagnostopoulos, and Dimitrios Pezaros. ”Predictive intelligence to the edge: impact on edge analytics”. *Evolving Systems*, 9(2), Aug. 2017, pp. 95-118. DOI:10.1007/s12530-017-9190-z
- Natascha Harth, Kostas Delakouridis, and Christos Anagnostopoulos. ”Convey intelligence to edge aggregation analytics.” *New Advances in the Internet of Things*. Springer, Cham, June 2017. pp. 25-44. DOI: 10.1007/978-3-319-58190-3 2


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Thank you and looking forward to the Questions!
http://www.dcs.gla.ac.uk/essence/
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