A PERFORMANCE COST/BENEFIT ANALYSIS OF ADAPTIVE COMPUTING IN THE TACTICAL EDGE

NATO IST-193 RESEARCH TASK GROUP

Alessandro Amato
Roberto Fronteddu
Raffaele Galliera
Niranjan Suri
Florida Institute for Human and Machine Cognition (IHMC), Pensacola, FL, USA

Harrie Bastiaansen
Willem Datema
Johan van der Geest
The Netherlands Organisation for Applied Scientific Research (TNO), The Hague, The Netherlands

Thomas Kudla
Fraunhofer Institute for Communication, Information Processing and Ergonomics, Wachtberg, Germany

Pablo Sanchez
University of Cantabria, Santander, Spain

Susan Watson
Defence Research and Development Canada, Ottawa, Canada

Mattia Fogli
University of Ferrara, Ferrara, Italy

THE WORK OF NATO IST-193 RTG

We aim to explore new **architectures** and **technologies** to make the ‘ocean-of-data’ readily and seamlessly available in a theatre-independent (multi-national) tactical mission context [1] to:

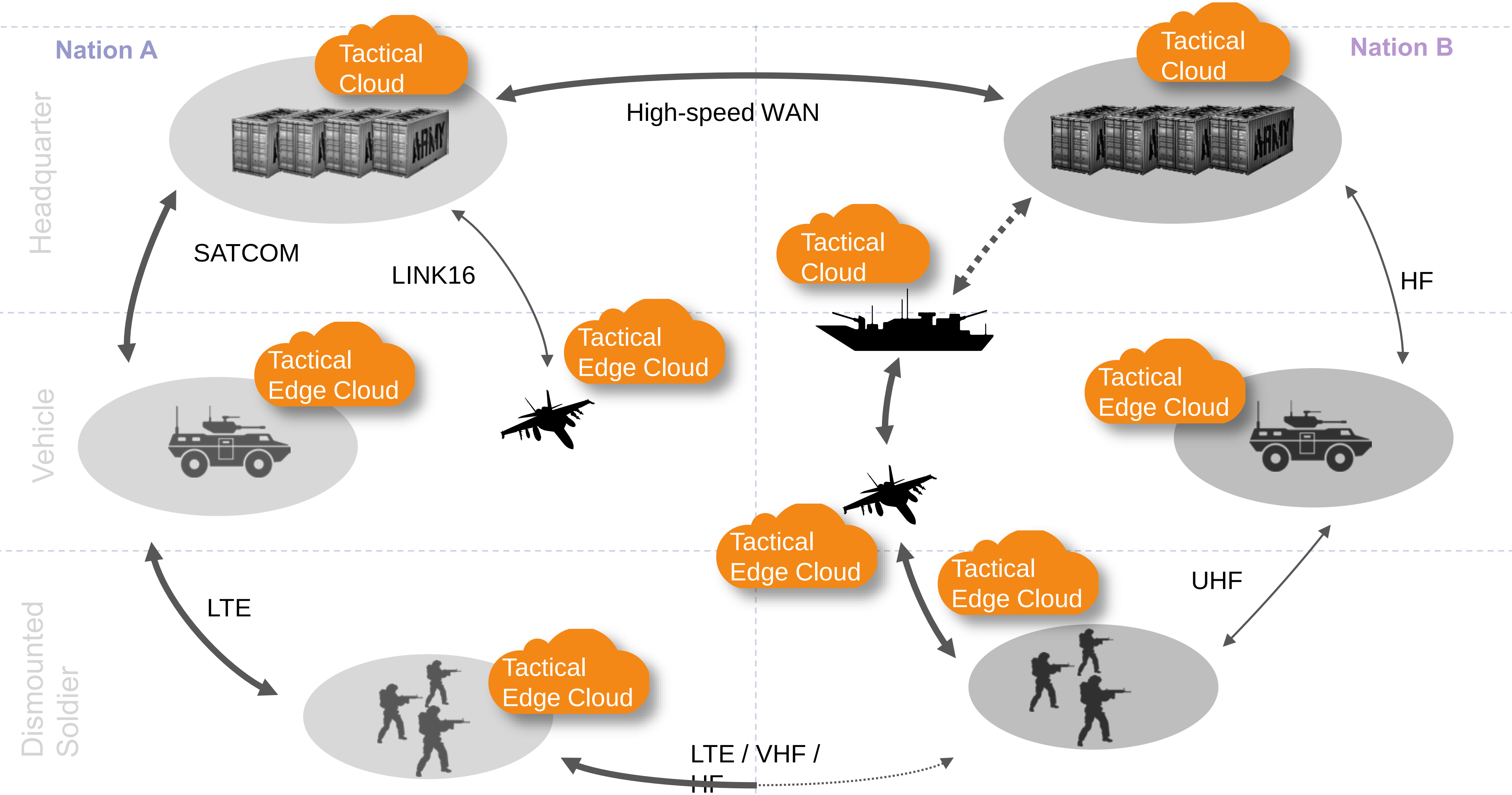
- leverage resources of partners
- improve situational awareness
- enhance resilience

THE WORK OF NATO IST-193 RTG

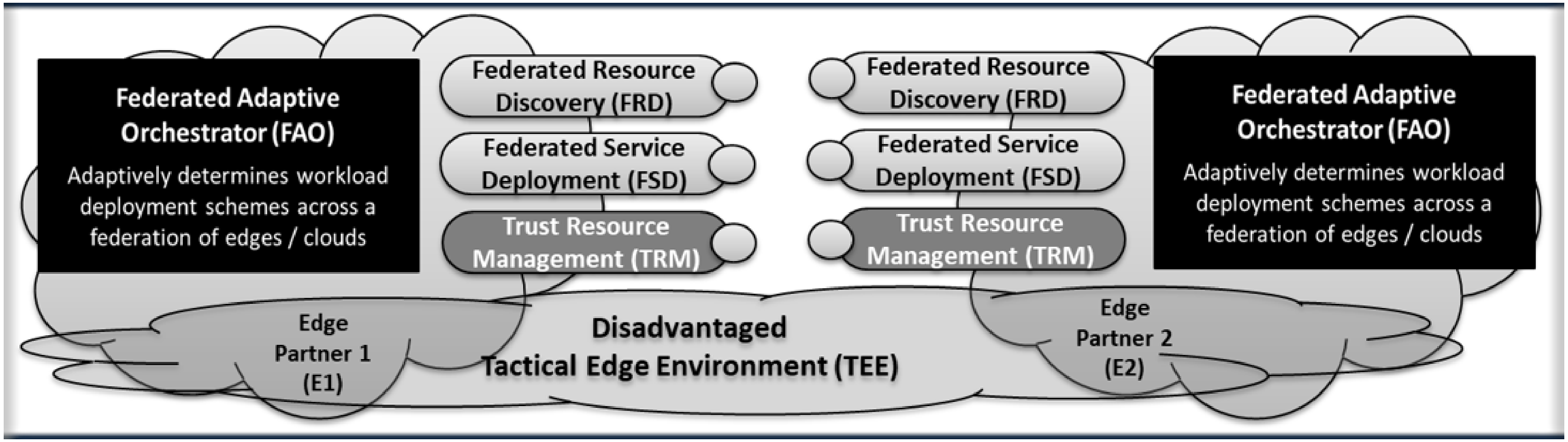
Objective of the **architecture** and **technologies** for tactical edge computing is to:

- optimize adaptivity in information processing and workload orchestration across a federation of tactical clouds
- ensuring fine-grained resource control for mission partners
- encouraging resource sharing.

FEDERATION OF (MULTI) NATIONAL TACTICAL (EDGE) CLOUDS



HIGH-LEVEL ARCHITECTURE



FAO

is responsible for creating deployment plans across the federation

FRD

provides information on both available services (available for deployment and already deployed) and resources (e.g., CPUs, RAM, storage)

FSD

is responsible for deploying services either on its own cloud or on other available clouds

TRM

is responsible for monitoring activities in a single federated cloud and updates its policies that other services, namely the FSD, FRD, FAO, must enforce

EXPERIMENTS

- Scenario for the Experiment
- Testbed Setup
- Performance Parameters: Adaptivity Costs and Benefits
- Results

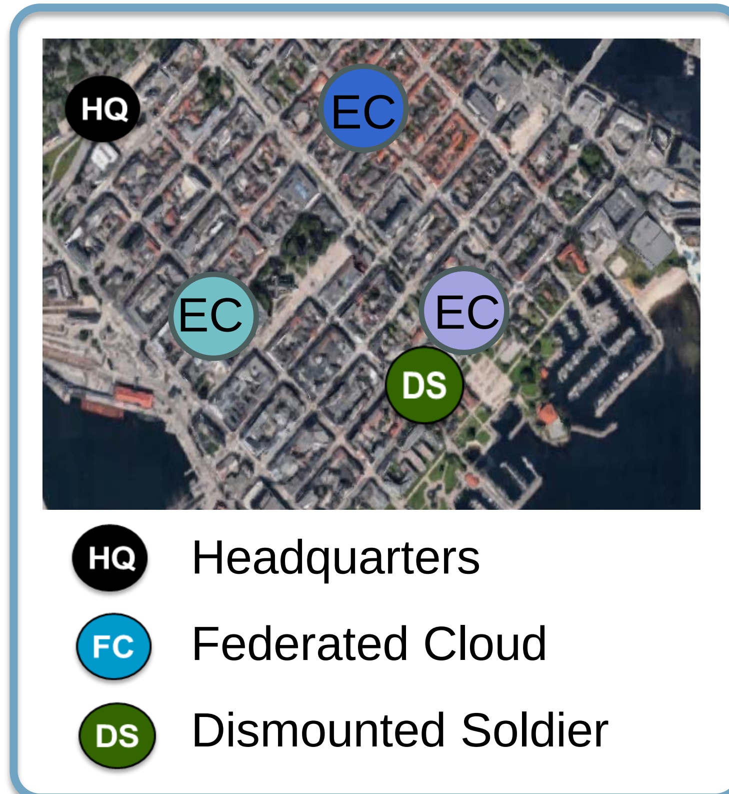
SCENARIO

Scenario: Vehicle Recognition and Tracking

- joint NATO military mission in an urban area
- mission partners operate a federated and adaptive infrastructure
- a dismounted soldier sees a suspicious car speeding away from its location

First Stage (simplified)

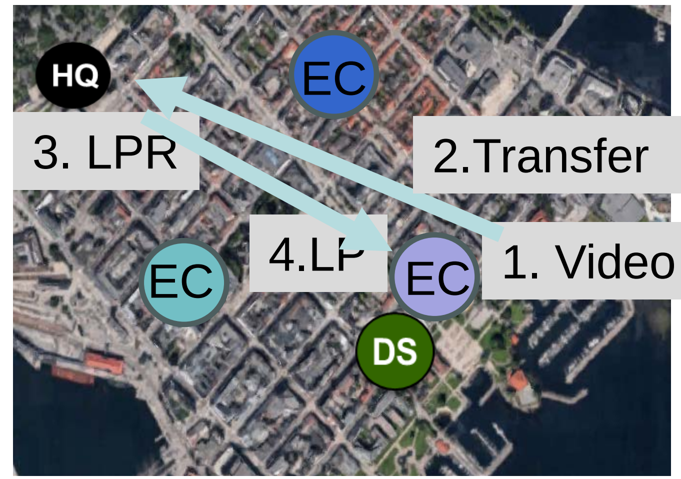
- soldier takes video footage of the car



SCENARIO

First Stage (simplified)

1. video is uploaded to a nearby vehicle of the soldier’s nation, being part of the federated and adaptive tactical cloud
2. Transfer Video
3. EC initiates a processing intensive license plate recognition service on HQ
4. Result of LPR gets returned



HQ Headquarters

FC Federated Cloud

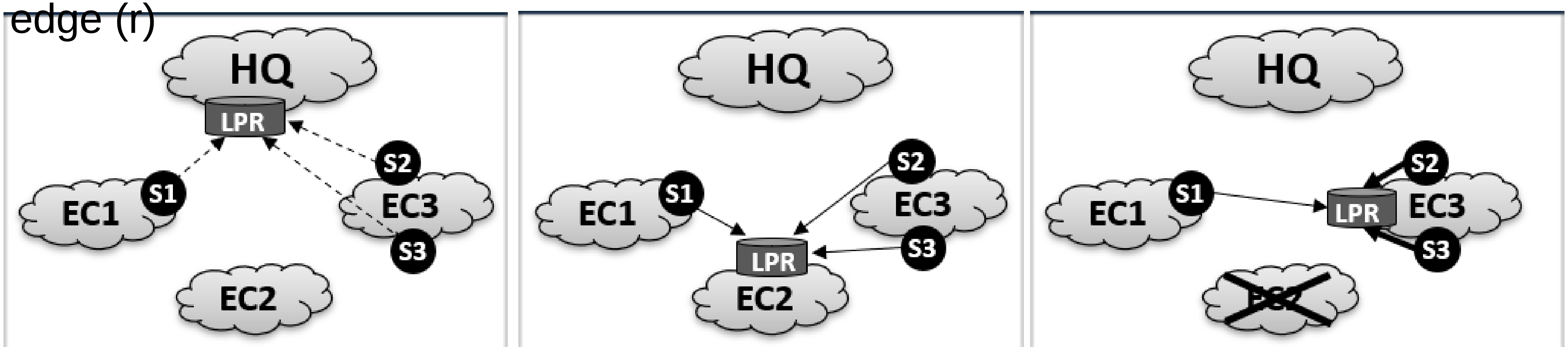
DS Dismounted Soldier

SCENARIO

Second Stage (simplified)

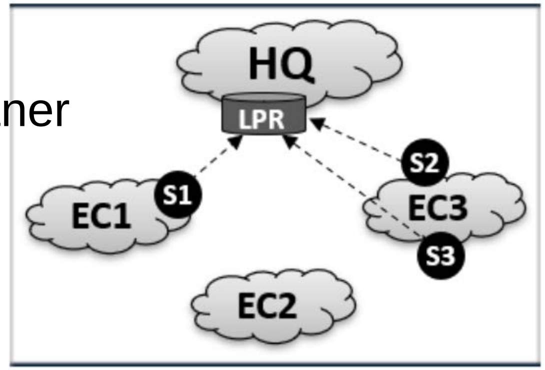
- Car ist identified as ‚suspicious‘
- Track car throughout the city using cameras on mission partner vehicles

Tactical edge cases: no tactical edge (l), static tactical edge (m) and adaptive tactical edge (r)



Parameters	Value
EC-to-HQ Available Bandwidth	256 Kbit/s
EC-to-EC Available Bandwidth	1,000 Kbit/s
Low-Resolution Video Size	0.5 MB
High-Resolution Video Size	13.0 MB

Testbed



- Four clouds, each owned by a different mission partner
- EC1, EC2, and EC3 and one cloud is HQ

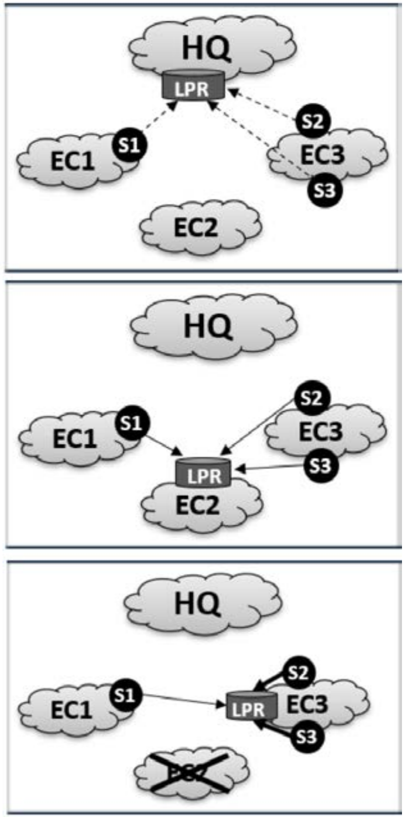
- In each cloud:
  - one VM for Kubernetes control plane
  - two VMs as workers
- HQ differs from the mission partner clouds in that its worker VMs have enhanced resources (doubled)

- The emulation of the tactical edge environment (TEE) is achieved using **EMANE** (for Extendable Mobile Ad-hoc Network Emulator [2])
  - EMANE was used to constrain EC-to-HQ and EC-to-EC communication links
- **SENSEI** (for Smart Estimation of NEtwork State Information [3]) is a microservice-based framework designed to perform network resource discovery and distribution over constrained tactical networks
- The **LPR** service is a distributed Deep Learning (DL) application designed for recognizing license plates in video footage

Performance Parameters: Adaptivity Benefits and Costs

Adaptivity Benefit Metrics

Benefits of adaptivity in a TEE is the performance gain for concurrent service requests



Adaptivity Cost Metrics

Costs to support adaptivity in a TEE

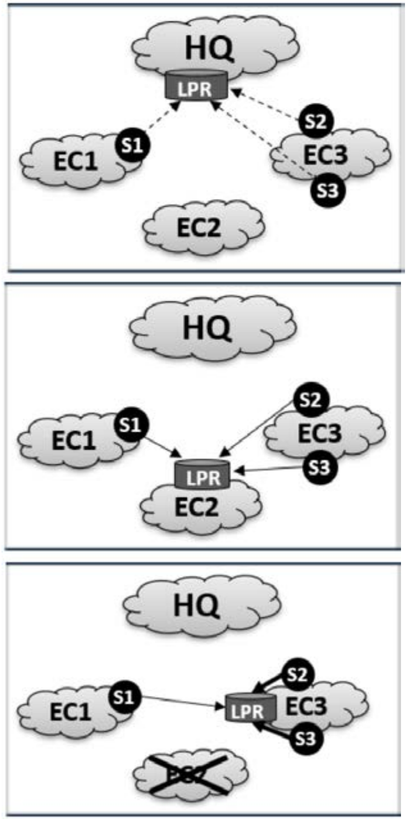
- Bandwidth impact
  - Inter-cloud communications
- Time efficiency of the FAO service
  - Duration required by the FAO service to create a deployment

- Performance cost of the FRD, FSD, and FAO services
  - CPU & RAM usage of the FRD, FSD, FAO
  - network bandwidth usage of the FRD & FSD

Results - Adaptivity Benefits

Response time* [s] of LPR service

Case	Video Size [MB]	No. Concurrent Requests		
		1	2	3
No Tactical Edge (HQ-to-EC, 256Kbit/s)	0.5 13	150 616	179 660	224 1072
Static Tactical Edge (EC-to-EC, 1Mbit/s)	0.5 13	150 312	159 316	208 443

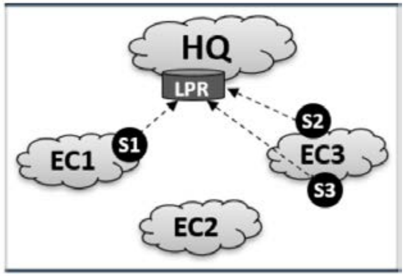


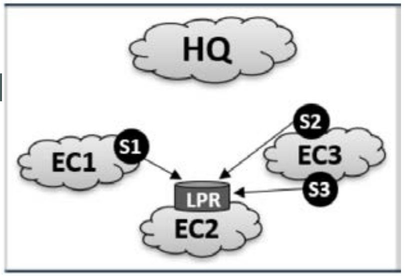
*Response Time: video transfer & processing

Results - Adaptivity Benefits

Response time* [s] of LPR service

Case	Video Size [MB]	No. Concurrent Requests		
		1	2	3
No Tactical Edge (HQ-to-EC, 256Kbit/s)	0.5 13	150 616	179 660	224 1072
Static Tactical Edge (EC-to-EC, 1Mbit/s)	0.5 13	150 312	159 316	208 443





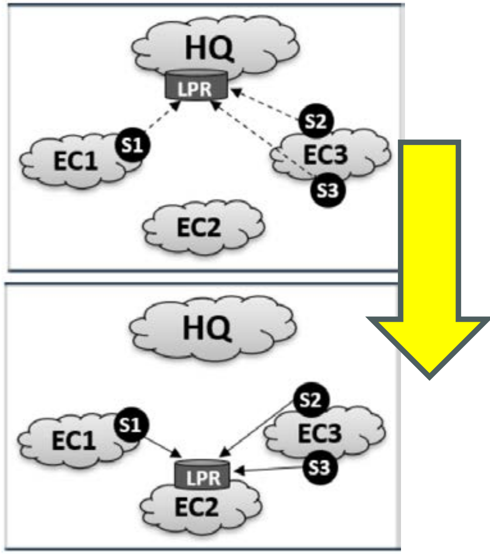
- Significant performance gain for using a tactical edge when simultaneously many concurrent service requests occur
  - Due to improved transfer times

Results - Adaptivity Benefits

Response time* [s] of LPR service

Case	Video Size [MB]	No. Concurrent Requests		
		1	2	3
No Tactical Edge (HQ-to-EC, 256Kbit/s)	0.5 13	150 616	179 660	224 1072
Static Tactical Edge (EC-to-EC, 1Mbit/s)	0.5 13	150 312	159 316	208 443

- Adaptivity in the edge architecture may take care of dynamic transition

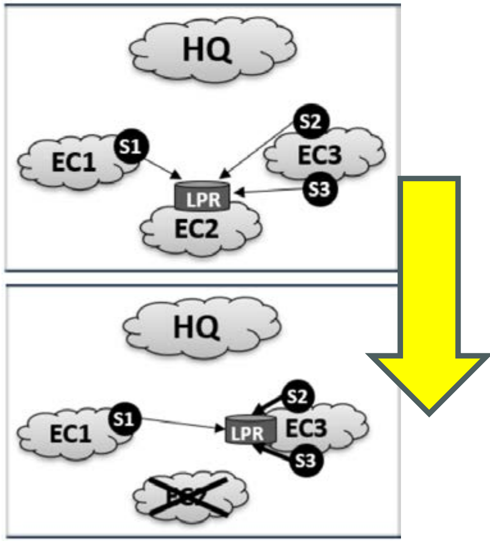


Results - Adaptivity Benefits

Response time* [s] of LPR service

Case	Video Size [MB]	No. Concurrent Requests		
		1	2	3
No Tactical Edge (HQ-to-EC, 256Kbit/s)	0.5 13	150 616	179 660	224 1072
Static Tactical Edge (EC-to-EC, 1Mbit/s)	0.5 13	150 312	159 316	208 443

- Performance gain of adaptivity arises when a tactical edge running the LPR service instance becomes completely unavailable (adversarial activities/ moving out of range)

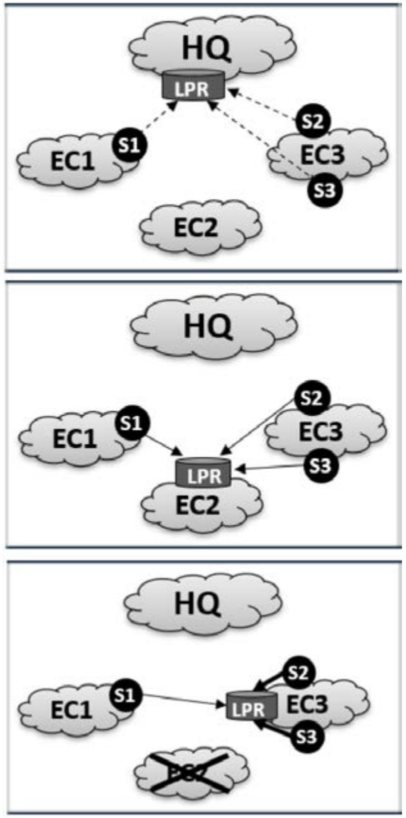


Results - Adaptivity Costs

- Bandwidth impact
  - Intern-cloud communications for FRD & FSD & SENSEI
  - Depends of
    - number of federated clouds in the TEE
    - frequency of the interactions
    - amount of data being transferred per

Service	Traffic In [Bytes/s]	Traffic Out [Bytes/s]
FRD	246.75	21.62
FSD	0	0.33
SENSEI	1545	1545

- For the FRD service, the amount of data being transferred per interaction depends on the number of resources being exchanged (OCI Images, etc.)

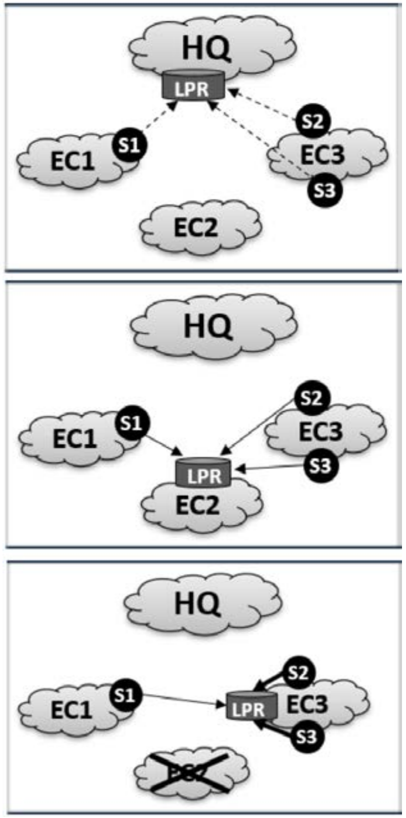


Results - Adaptivity Costs

- Time efficiency of the FAO service (10k Updates)

Percentile				
50th	75th	90th	99th	99.9th
0.65	0.77	0.94	2.13	2.46

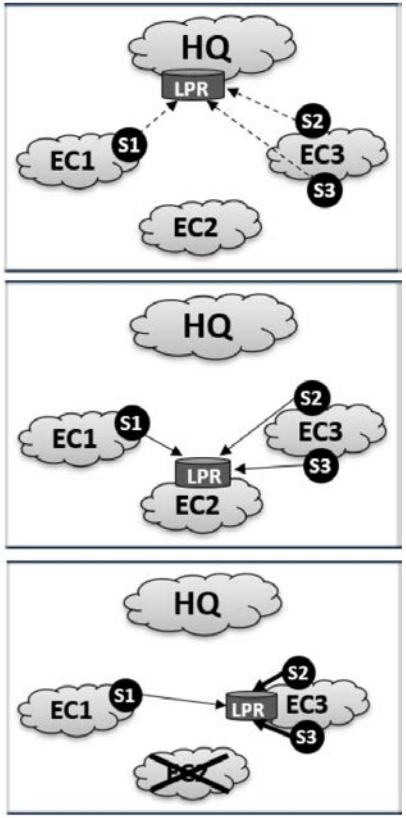
- An update is
  - Reallocation of the LPR service from EC2 to EC3, triggered by EC3 going offline
  - Duration for the time taken by the FAO service from the moment the FRD service updates the resources, to the point where the FAO modifies its existing deployment plan.



Results - Adaptivity Costs

- Performance cost of the FRD, FSD, and FAO services
  - CPU & RAM usage of the FRD, FSD, FAO

Service	CPU [milliCPU]	Memory [MB]
FRD	230	106.05
FSD	20	241.61
FAO	30	119.43



- services are very frugal
- More complex scenarios may be more challenging
  - especially for the FAO,
    - which would be needed to make more difficult and/or frequent orchestration decisions.

CONCLUSIONS

1. Static solutions that do not adapt dynamically to changing circumstances, could fail due to the high variability that typically occurs at the tactical edge
   - Node mobility, adversarial actions may cause network disconnections or node failures. Hence, a dynamic approach is necessary that can re-orchestrate deployed workflows when circumstances change.
2. The bandwidth impact and performance cost of adaptivity is relatively low

3. BUT:
   - Experimental network used was fairly simple, with just a handful of nodes
     - Bandwidth impact is low
     - FAO times are low

4. Future Work:
   - Enhance the number of nodes
   - More complex scenarios
   - more complex services

REFERENCES

1. Bastiaansen, H., Van Den Broek, C., Kudla, T., Isenor, A., Webb, S., Suri, N., Masini, A., Bilir, C. & Cocelli, M. 2019, "Adaptive Information Processing and Distribution to Support Command and Control in Situations of Disadvantaged Battlefield Network Connectivity",*2019 International Conference on Military Communications and Information Systems, ICMCIS 2019*
2. U.S. Naval Research Laboratory. "Extendable Mobile Ad-hoc Network Emulator (EMANE)". https://www.nrl.navy.mil/Our-Work/Areas-of-Research/Information-Technology/NCS/EMANE.
3. R. Fronteddu, A. Morelli, E. Casini, N. Suri, B. Jalaian and L. Sadler, "A content and context-aware solution for network state exchange in tactical networks," MILCOM 2017 - 2017 IEEE Military Communications Conference (MILCOM), Baltimore, MD, USA, 2017, pp. 430-435, doi: 10.1109/MILCOM.2017.8170825.

THANK YOU FOR YOUR ATTENTION

DEMO AT 15:50

NATO IST-193 RTG

EDGE COMPUTING AT THE TACTICAL EDGE