Distributed Autonomous and Resilient Emergency Management System (DARE): A 5G Perspective

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About the Project

- Distributed Autonomous and Resilient Emergency Management Systems (DARE)
- Funded by: Engineering and Physical Science Research Council (EPSRC), UK
- Scheme: Global Challenge Research Fund (GCRF)
- Project Duration: May 2017 to April 2020 (3 Years)
- Project Partners:

Kingston University London | University of Surrey | University of Glasgow | University of Malaya

- Advisory Board: O2, BT, Huawei, UbiTech
- Operational Budget: £1.3 million
- Target: Analytical solutions and testbed design

Aim of the Project

- *To improving the resilience of critical infrastructure and essential services to severe disruption from natural hazards*
- *DARE to be founded upon multiple communication platforms: wireless sensor networks (WSNs), machine to machine (M2M) networks, WiFi/Ad-hoc/Mesh-based cooperative ubiquitous networks and future cellular networks (5G and beyond)*

- *Advanced network routing, radio access network architecture design and advanced computing algorithms including machine learning and computational intelligence*

- *Testbed design on the 5G framework (MIMO, mmWave, D2D communication, dense HetNet) and the computer simulation study of the DARE network*

5G Requirements

- The 'full' 5G System includes:

  eMBB (enhanced Mobile Broadband)

  URLLC (Ultra Reliable Low Latency Communications)

  mMTC (massive Machine Type Communications)

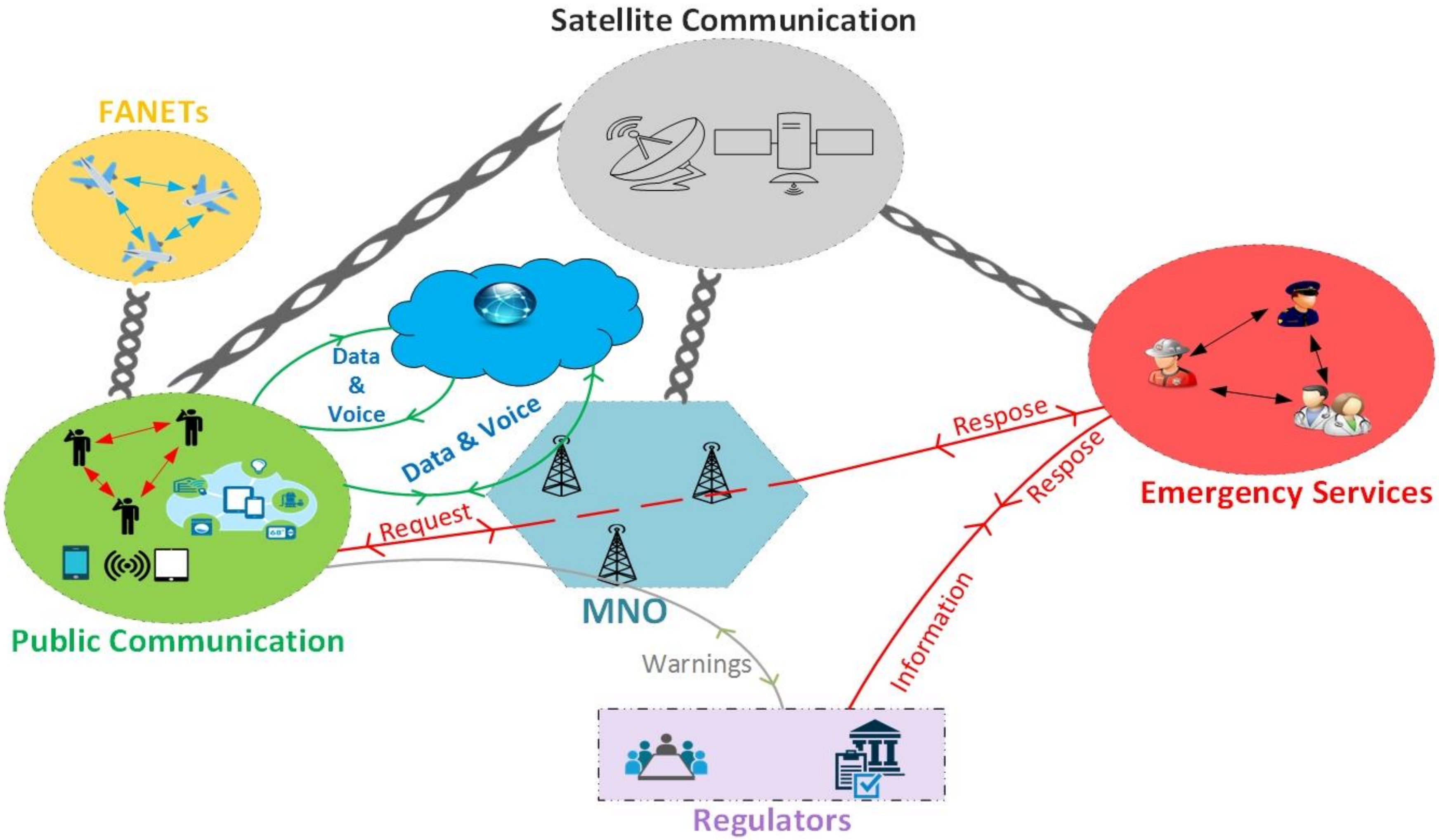
- Higher carrier frequency (sub GHz band)
- Larger bandwidth (>100 MHz) → Carrier aggregation
- Large antenna array (due to short wave length) → Beamforming
- Device-to-device (D2D) communication
- Network densification and HetNet

- Post-disaster communication requirements:

a) Network connectivity/coverage is more important than throughout

b) Convergence of multiple wireless communication technologies

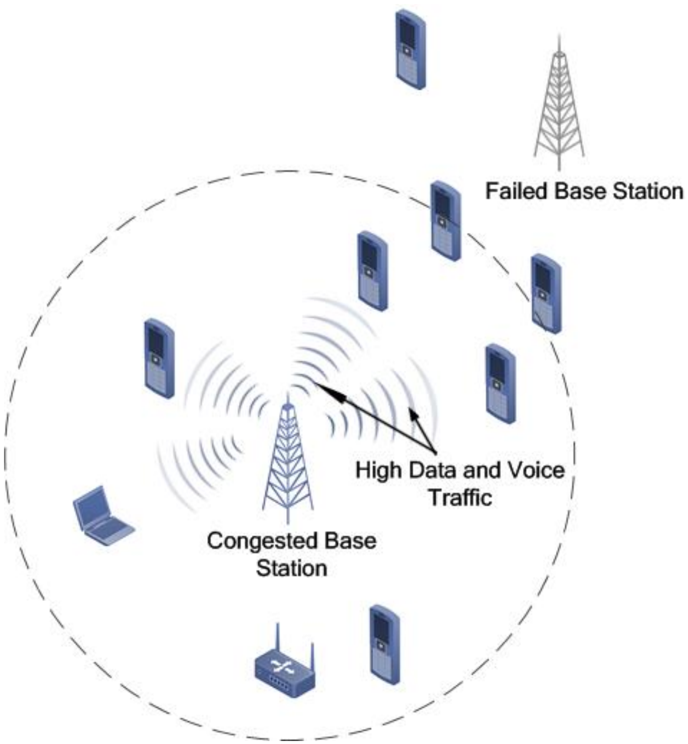
Overview of Post-Disaster Communication



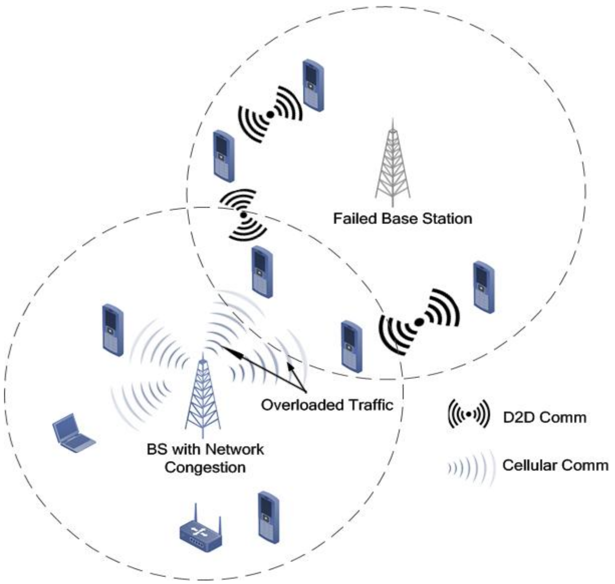
A typical post-disaster network scenario: convergence of multiple technologies

Post-Disaster Wireless Network Architecture

- Based on our study, there are three main network models in post-disaster scenario which need unique solution for each.
    - Congested Network
    - Partially Connected Network
    - Isolated Network
- Congested Network: When subset of functioning BSs (in post-disaster) receives user data/voice traffic more than BSs can handle.....
- More Traffic – Less power supply – less processing capacity
- Priority group/ Priority Services
- Machine learning for optimal radio resource allocation



Post-Disaster Wireless Network Architecture….

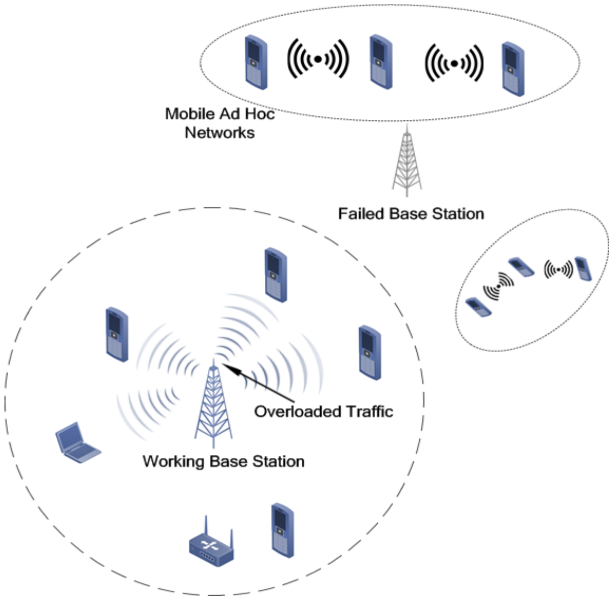


- Partially Connected Network: When the BSs are partially damaged, subset of users or emergency services are disconnected.
- D2D/multi-hop D2D to provide better network coverage and lower energy consumption

- Spectrum allocation for underlay D2D
- UAV-assisted D2D communication

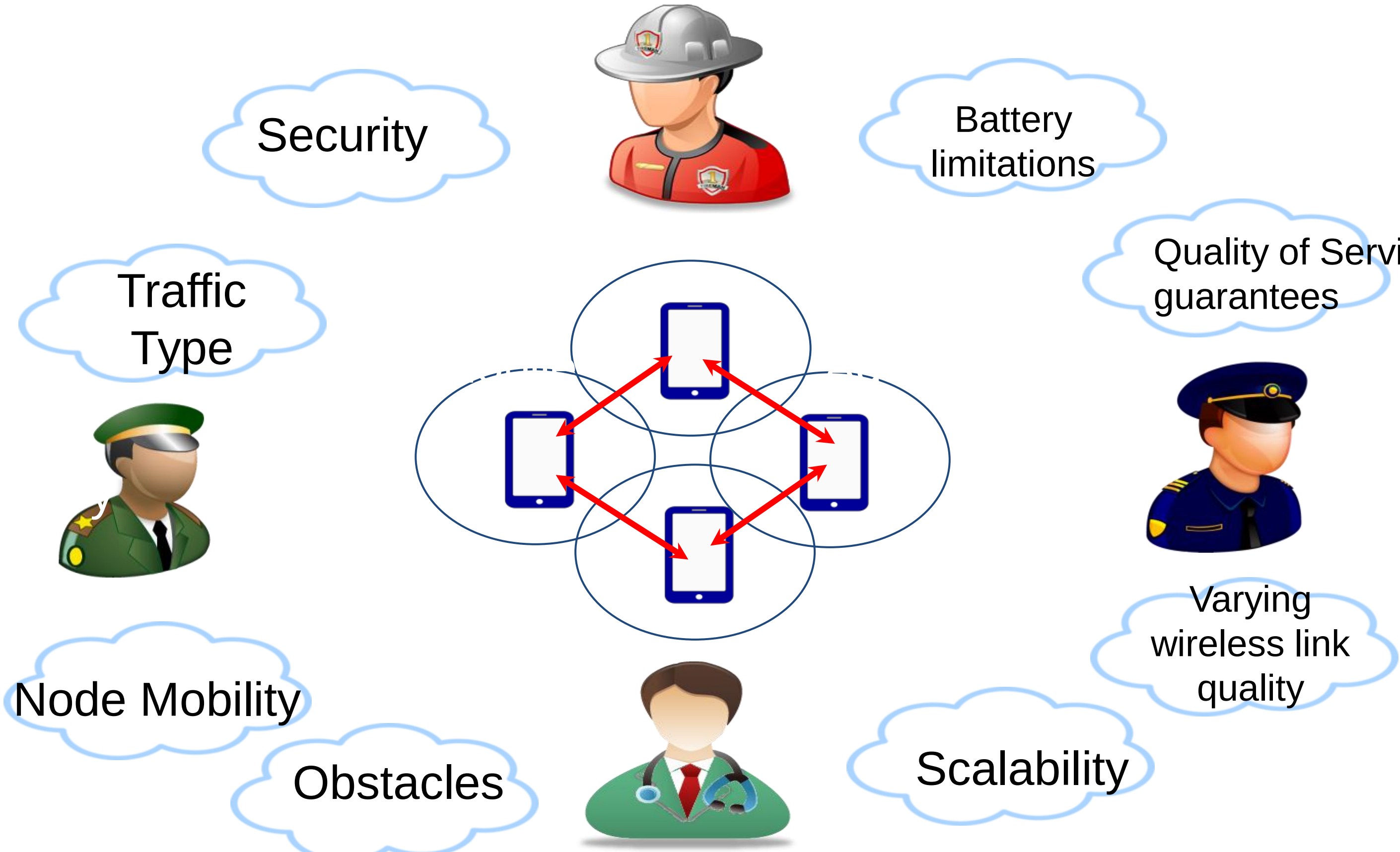
- Isolated Network: Users do not receive any control signals from BSs
- MANET could be formed among users
- Efficient routing protocol and signalling (e.g., ChaMeLeonV2 has been developed)

- Autonomous route formation towards BSs
- Higher energy efficient routing protocols



Mobile Ad Hoc Networks

- MANETs and Machine Learning based Routing Protocols – DARE Perspective
- Operate in decentralized mode (no need for access point)
- Proposed Routing Protocols - Multipath ChaMeLeon version 2 (M-CMLv2)*

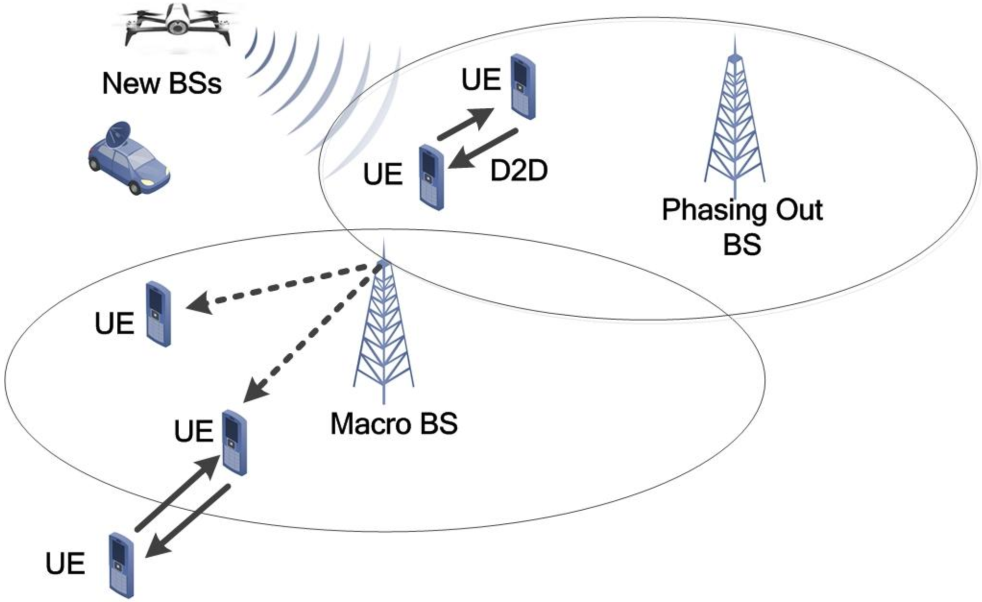


*Ladas, Alexandros, G. C., Deepak., Pavlatos, Nikolaos, and Politis, Christos., "A Selective Multipath Routing Protocol for Ubiquitous Networks". Elsevier Ad Hoc Networks Journal, vol. 77, pp. 95-107, 2018

D2D Communication for Post-Disaster Scenario

- During typical post-disaster scenarios, network events are:
- Base Stations Thinning Process due to dysfunctional Base stations
- Base Station Superposition, when new BSs (vehicular or UAVs) are added
- D2D Route Formation overlaying cellular communication.

- Improved network coverage
- *Network throughout is less important then the network coverage during the golden hour of post-disaster network scenario.*



D2D Communication for Post-Disaster Scenario…

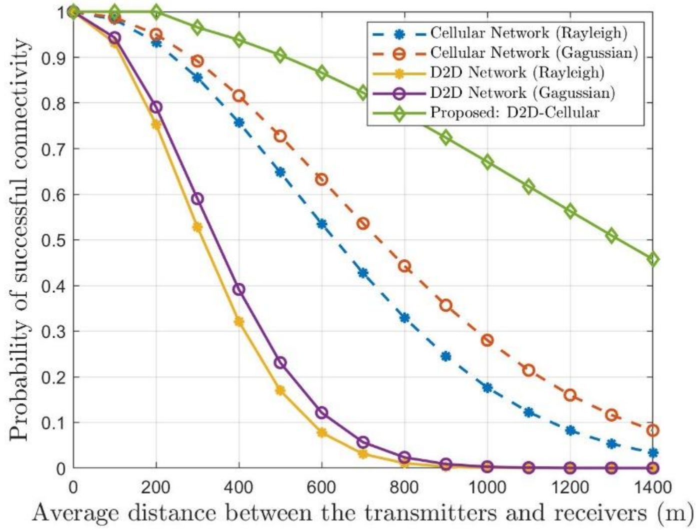
D2D Communication and UAVs for Reliability and Connectivity:

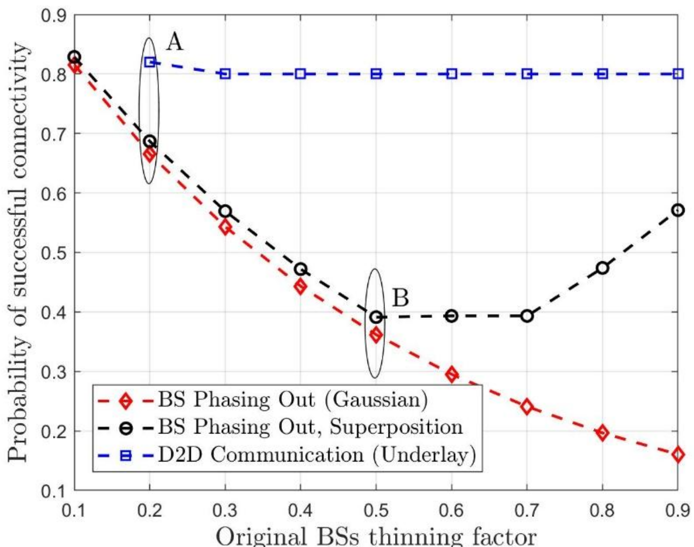
- D2D communication, mobile BS and UAVs for partially-isolated network during post-disaster to provide better coverage.
- The mathematical analysis of post-disaster network to understand the network behaviour in such scenarios.
- BS thinning, BS superposition, D2D pair formation, Optimal UAV positioning
- BS thinning → dysfunctional BSs,
  BS superposition → added BSs (e.g., UAVs)
  (Both Occurs simultaneously during particular post-disaster scenario)
- Both of them preserve the original point process
- In addition, when both happens simultaneously, it preserves the point process. (PPP → PPP)

D2D Communication for Post-Disaster Scenario…

D2D Communication and UAVs for Reliability and Connectivity:

- In this work the BSs and users distribution follow the Poison point process
- It has been studied that how does it behave when it undergoes thinning of BS and superposition of BSs or D2D link formation
- Additional BSs have been considered in terms of UAVs (mostly LOS comm.)
- From energy efficiency point of view, the users are forced to either cellular or D2D mode (X and Y: independent and mutually exclusive events)





UAVs for Post-Disaster Communication

- It can maintain better communication channels → higher chance of short-distance line of sight communication
- UAVs → {ubiquitous coverage, relaying unit, data collection}
- *Energy Consumption = Radio Energy + Propulsion Energy*
- Following are the targets:

  a) Optimization of altitude of UAVs for maximum coverage

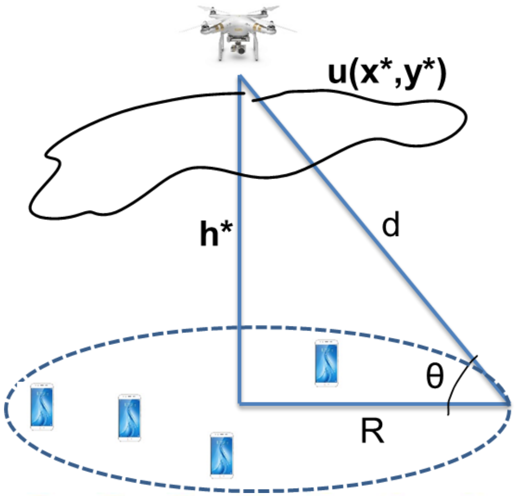
  b) Optimization of UAVs distribution to improve energy efficiency

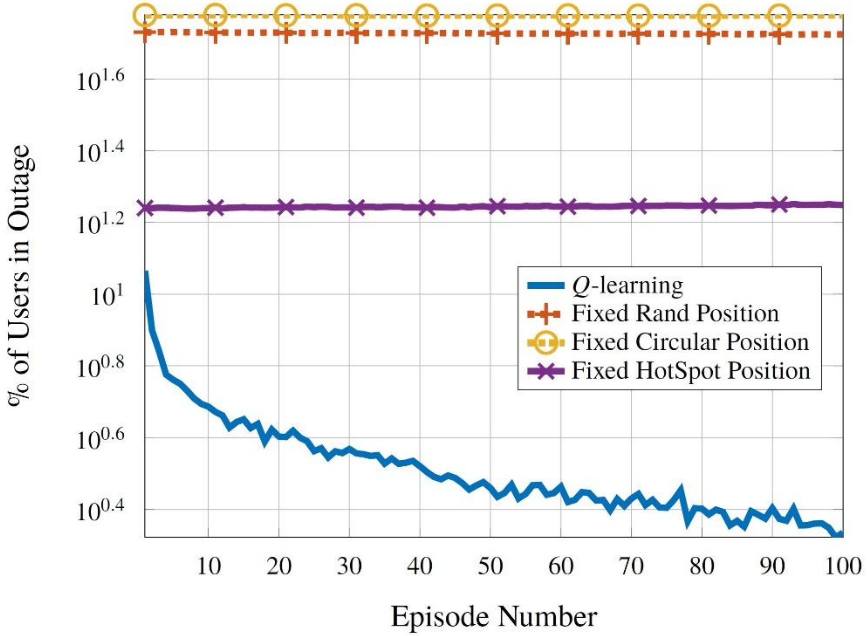
  c) Optimization of trajectory of UAVs to cover maximum users

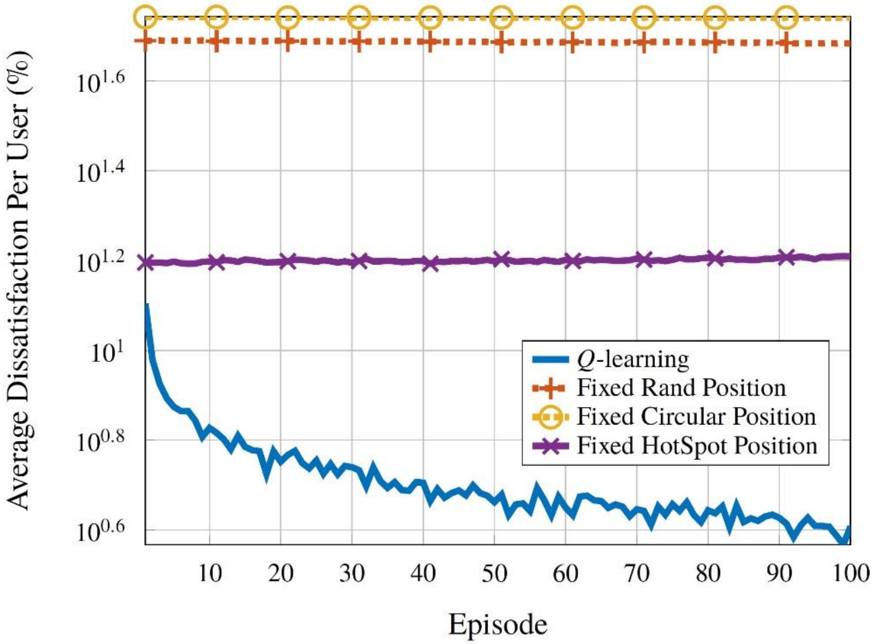
- Machine Learning approach: The UAVs must have learning capability to improve the energy efficiency and maximize the coverage
- Reinforcement Learning (Q Learning approach)

UAVs for Post-Disaster Communication

- Optimal height of UAVs to improve coverage
- Optimal trajectory of UAV
- Reinforcement Learning Approach to learn the optimal route the UAV takes
- Improvement in users in outage and lower dissatisfaction users due to Q-learning algorithm







**Paulo Valente Klaine, João Pedro Battistella Nadas, Richard Demo Souza, Muhammad Ali Imran, "Distributed Drone Base Station Positioning for Emergency Cellular Networks using Reinforcement Learning", Cognitive Computation, 2018.*

DARE Overlaying 5G Testbed

- Verify the distributed, resilient and autonomous designs through simulations and real-world testbed implementations using existing ns-3, OPNET, MATLAB

- Testbed for network resilience and QoS support functionalities for an autonomous critical communication platform

- To be showcased to wider industrial and academic community, including GCHQ and Defense Science and Technology Laboratory (DSTL)

- The plan is to use the infrastructure provided by the SoftFIRE testbed, currently deployed at the **University of Surrey** (5GIC).

Indoor portion of the testbed: over 1000 heterogeneous embedded devices, with different sensing capabilities, 6 indoor Lampsites and 6 access points.

Outdoor portion is a network: 14 outdoor 2xsector and 5 omnidirectional base stations creating a self-contained, small-scale, low-power mobile network.

Use of UAVs, subject to various legal requirements.

THANK YOU…