INTERNET OF THINGS IN SPACE

Connecting “things” with nanosatellite mega-constellations
OUTLINE

IoT use cases with satellites
CubeSats and the Delphini-1 mission
Mega-constellations
Challenges for routing and mobility
Future space-air-ground integration
IOT CHARACTERISTICS

Connectivity
Small devices online

Coverage
Widespread (geographical)

Scale
Large number of units

Resource constraints
Efficient use of energy and radio resources

Cyber Security
IOT USE CASES

Global asset tracking
- Ships/airplane tracking
- Tracking of goods
- Herds tracking

Event detection/alert
- Surveillance
- Natural hazards: volcanic eruptions, tsunami, space weather, etc.

IoT aggregation
- Sensor and actuator networks
- Earth observations & environmental monitoring

Telecommunications
- Voice and data
- Backup access
- Incident area network
- Relay for other networks
DELPHINI-1 MISSION

5 December 2018 • 31 January 2021 • 14 March 2021

Experience the launch
CUBESAT
THE NEW IOT EDGE DEVICE

Embedded computer; limited processing capability;
limited RAM
Limited power supply; harvesting & storage
Flash memory
Low-power radios

Typical (minimum) CubeSat sensors setup
  - 6 sun sensors
  - 3 axis magnetometer
  - 3 axis gyro
  - temperature

Source: GomSpace (2017)
CUBESAT
THE NEW IOT EDGE DEVICE
DELPHINI-1 IMAGES FROM SOUTHERN HEMISPHERE
MEGA-CONSTELLATION DESIGN

- LEO orbit: 300 km – 1000 km
- Network design 10/4/0°
- Static/dynamic topology

- Resource-constrained devices
- Varying link-stability and link distance
- Large relative motion between some orbits
NANOSATELLITE DEPLOYMENTS

Source: http://www.nanosats.eu/
COMMUNICATION CHALLENGES

Intersatellite links (LOS/NLOS)
Up/downlink data throughput
Medium access control
Routing
Mobility management
AD HOC DISTANCE VECTOR (AODV) ROUTING

• Designed to handle a relatively high topological dynamics.
• Key protocol messages:
  — Route Request (RREQ)
  — Route Reply (RREP)
  — Route Reply Acknowledgment
  — Route Error
• Depth of route search follows the expanding ring mechanism controlled by TTL
• Links “freshness” is controlled by an Active Route Time out
AODV SIMULATION

Packet Delivery Rate (PDR) as function of Active Route Timeout.

- PDR is given by the % of total number of received packets in the network with respect to total number transmitted.

8-20 constellation

Active Route Timeout fixed at 200 s

Marcano et al. On Ad hoc On-Demand Distance Vector Routing in Low Earth Orbit Nanosatellite Constellations, VTC2020-Spring, 2020
THE MOBILITY CHALLENGE

End-to-end communication

Application
Transport (UDP)
Network (IPv6)
Data Link
Physical Link

Network (IPv6)
Data Link
Physical Link

Network (IPv6)
Data Link
Physical Link

Application
Transport (UDP)
Network (IPv6)
Data Link
Physical Link

GS / MTC Gateway
C2G Link
M2M / IoT Devices

Resource-rich CubeSat
C2C Link

Resource-rich CubeSat
C2C Link

GS
C2G Link
NOC
THE MOBILITY CHALLENGE

“Double mobility problem”
- Both the mobile and the corresponding nodes are mobile

Frequent hand-over
- Relative short access times

Service characteristics
- Latency
- E2E link robustness
THE MOBILITY CHALLENGE

Routing breaks when a mobile IP node changes attachment to the Internet
Care-off-address (CoA)
Home agent & binding updates (control)
Route optimization

Currently investigating suitability of the different IP mobility protocols (IETF) for IP networks in space.
- MIP – Mobile IP
- PMIP – Proxy mobile IP
- DMM – Distributed Mobility Management
SPACE-AIR-GROUND INTEGRATED NETWORKS

GEO, MEO, LEO satellite constellations
High- and Low Altitude Platforms (HAPS and LAPS)
Mobile infrastructure integration
Backhaul network for IoT devices
Mega-constellations based on nanosatellites have become an option for connecting IoT devices potentially covering remote areas. Building, launching and operating nanosatellites can be done by “ordinary folks” \(\rightarrow\) Delphini-1.

Research and Innovation in new network technologies and services are needed \(\rightarrow\) Examples: routing and mobility.

A view on future space-air-ground integrated networks.
DISCO-2: The next student-led CubeSat from Aarhus University with partners
Crowd sourcing campaign just launched!
Visit: discosat2.dk