5G Integrated satellite terrestrial M2M/IoT networks

5G PPP – 1st 5G Architecture Workshop

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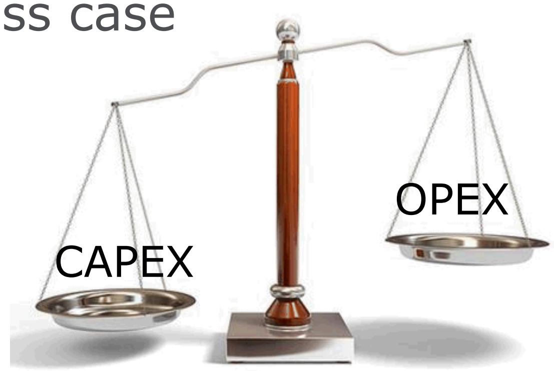
Key satellite M2M design drivers



- **Minimize terminal CAPEX** as it dominates business case
    - Highly integrated hardware
    - Low transmit power
    - Low duty cycle
- **Minimize OPEX** over satellite network
    - small forward link, efficient return link
    - simple network synchronization, resource allocation procedures, lower protocol overhead
    - Asynchronous: Random access-based with fewest re-transmissions
- **Flexibility/Scalability:** bit rates, network size, graceful growth of CAPEX and OPEX
- **Robustness and Reliability**: not dependent on local networks or power

Random Access Technologies

- Recent years witnessed a large growth of enhanced random access techniques with contention resolution capabilities
- Common concept is to perform more advanced signal processing at the gateway (memory based iterative successive interference cancellation)
- Modern RA techniques can achieve 2-3 order of magnitudes improvement in throughput at low packet loss ratio compared to ALOHA and/or Slotted ALOHA
- Several classes
    - slotted (TDMA/MF-TDMA), unslotted, spread-spectrum
- Among the many solutions, **Enhanced Spread-Spectrum ALOHA** (or its evolutions) is considered the most promising solution in terms of performance (throughput, power/energy efficiency, flexibility etc..)

Enhanced Spread Spectrum ALOHA (E-SSA)

Description: slightly modified version of the robust 3GPP W-CDMA random access waveform (asynchronous burst transmission). Enhanced processing at the gateway with sliding window memory based recursive Successive Interference Cancellation burst demodulator.

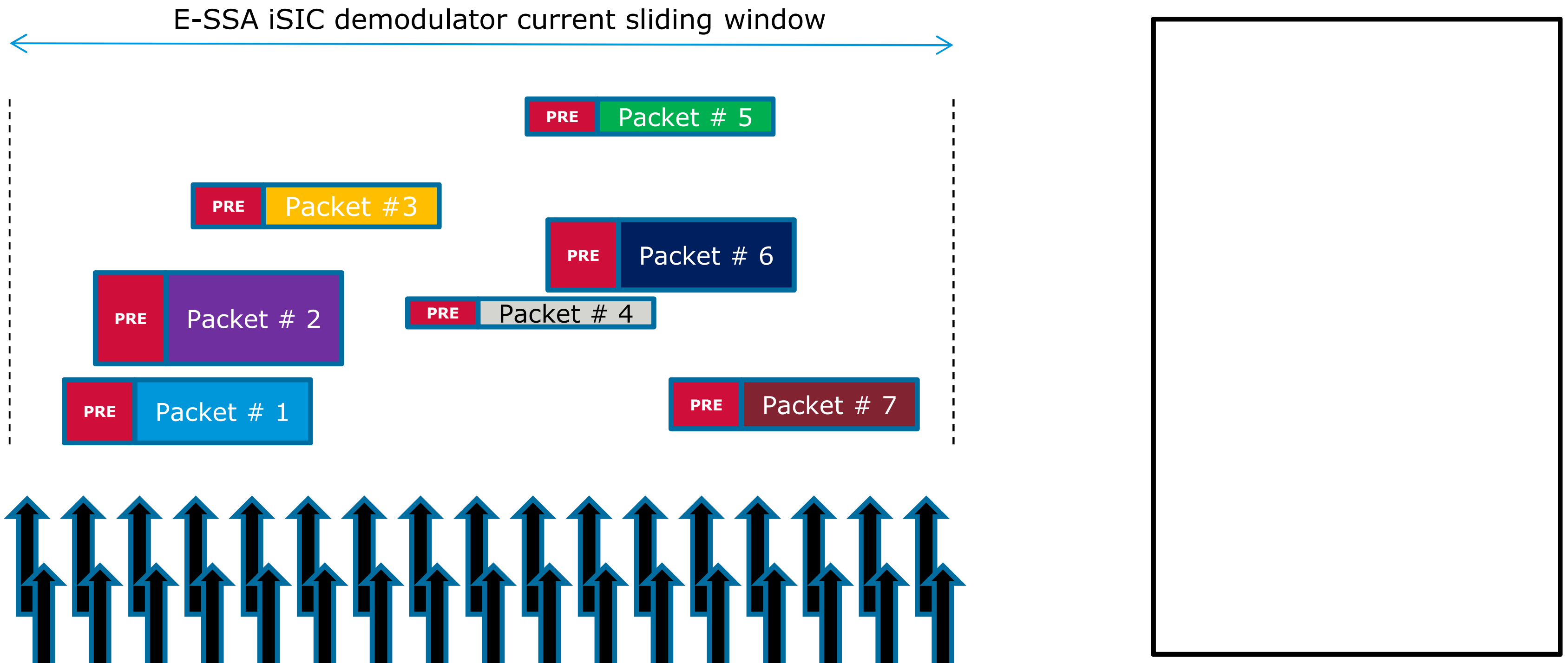
Benefits:

- Up to 3 bit/s/Hz of spectral efficiency achievable
- asynchronous random access channel 3000 times better than ALOHA!
- Low terminal EIRP and power consumption
- flexible bandwidth (200 kHz to 5 MHz) and multiple data rates achievable.
- Enhanced performance in presence of power unbalance.

Available applications: interactive services (M2M) in L/S-Band (S-MIM standard) / C/Ku/Ka-band (F-MIM), return link of the ANTARES aeronautical communication standard.

Maturity (TRL): Testing, working and existing prototypes (~5)

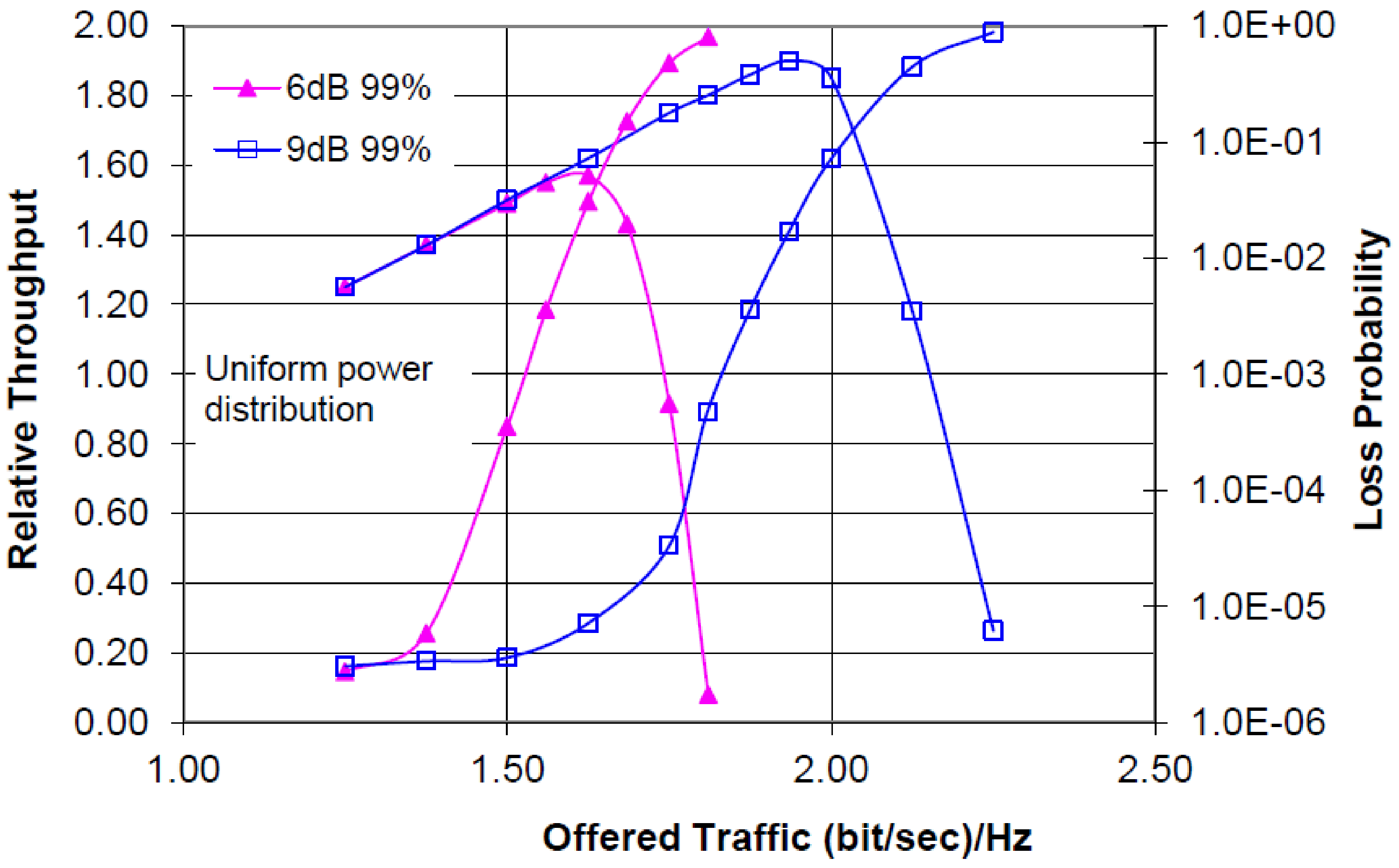
E-SSA Concept



Detected / Decoded / Cancelled Packets

The power unbalance among packets is depicted with different rectangular heights

Simulated E-SSA Performance



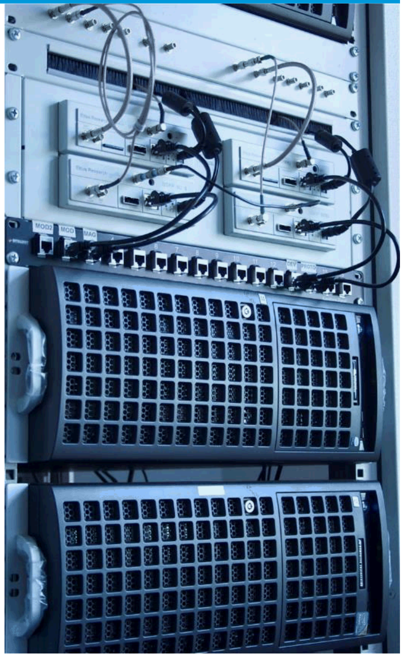
…but how many users?

- An effective rule of thumb is:
  - By knowing the achievable spectral efficiency, η
  - By knowing the available bandwidth, **W**
  - By knowing the single user data-rate, **R_b**
  - By knowing the average activity factor, **d**
  - A good approximation of the total users is: $N_U = \frac{\eta * W}{d * R_b}$

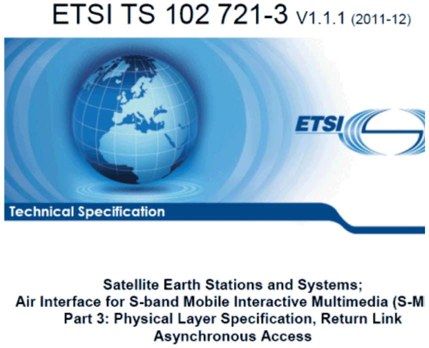
- An example:
  - η =1.8, **W**=300 kHz, **R_b** =5 kbit/s, **d**=1/3600 (every 1’ h)
    ➔ **N_U = 390’000 M2M terminals !**

E-SSA: Technology Maturity

- Mature technology field proven in the lab and extensively over the W2A S-band payload as well as Ka-sat and other FSS satellites
- Publicly available in ETSI standard (S-MIM)
- Adopted in the ANTARES Communication standard
- Full pre-commercial gateway available from MBI (Italy)
- ***Smart LNB***: Eutelsat's new interactive satellite terminal for iTV and M2M operating at C/Ku/Ka-band



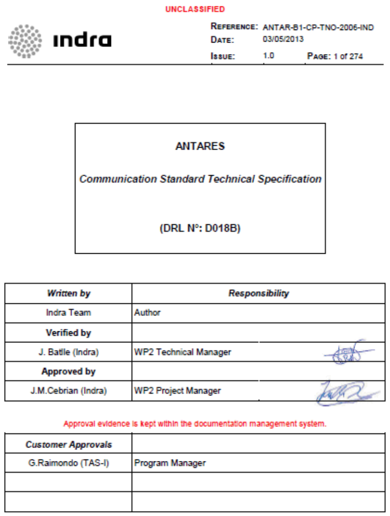
ESSADEM mbi



ETSI TS 102 721-3 V1.1.1 (2011-12)

Technical Specification

Satellite Earth Stations and Systems;
Air Interface for S-band Mobile Interactive Multimedia (S-M
Part 3: Physical Layer Specification, Return Link
Asynchronous Access



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ANTARES

Communication Standard Technical Specification

(DRL N°: D018B)

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Approval evidence is kept within the documentation management system.

Customer Approvals	
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User terminal prototype

S-MIM field trials in ARTES and EU projects

Contention Resolution Diversity Slotted ALOHA (CRDSA)

Description: Contention Resolution Diversity Slotted ALOHA is a random access technique for time slotted systems that transmits bursts in replicas and takes advantage of iterative interference cancellation at the demodulator side.

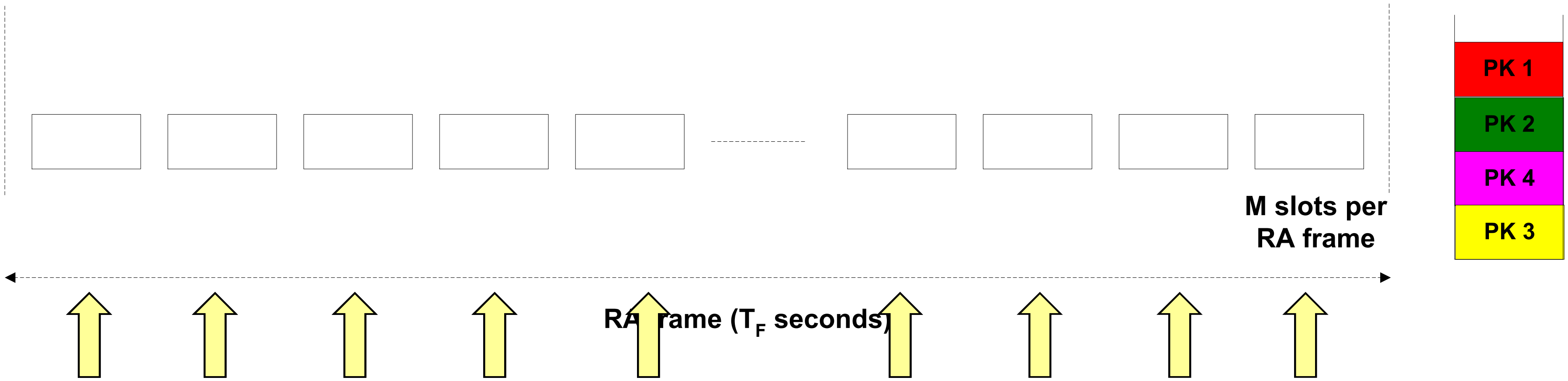
Benefits: Immense throughput improvement (1000 times compared to classical slotted ALOHA. Enhanced performance in the presence of power unbalance.

Available applications: Part of the DVB-RCS2 standard.

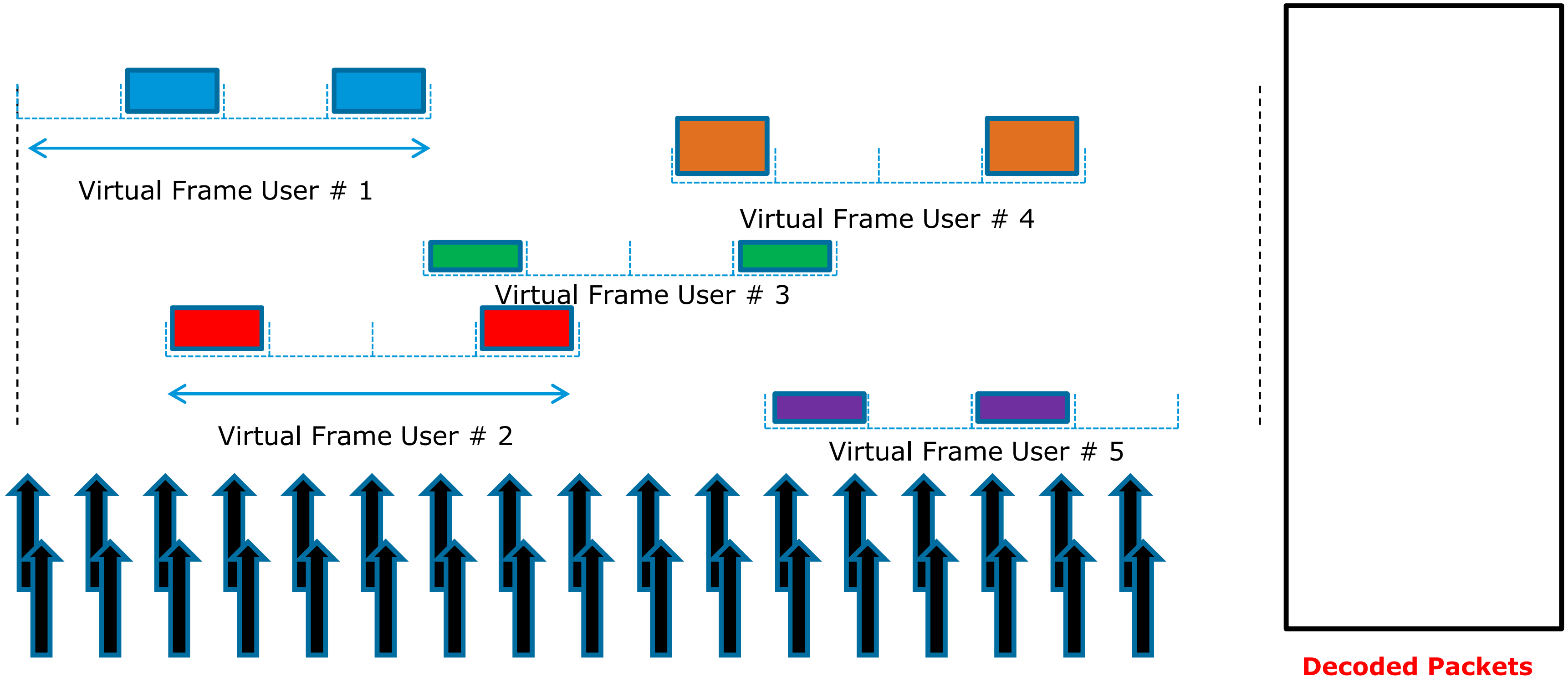
Can be easily incorporated in any MF-TDMA / slotted systems.

Maturity (TRL): Testing, working and existing prototypes (~5)

CRDSA Concept



ACRDA Concept



Current iSIC Demodulator Sliding Window

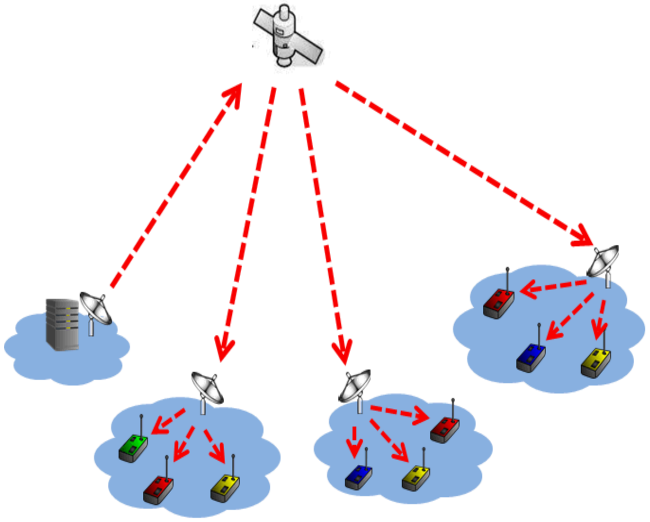
The power unbalance among packets is depicted with different rectangular heights

Impact of future signaling traffic on MAC for satellite M2M/IoT ICN networks

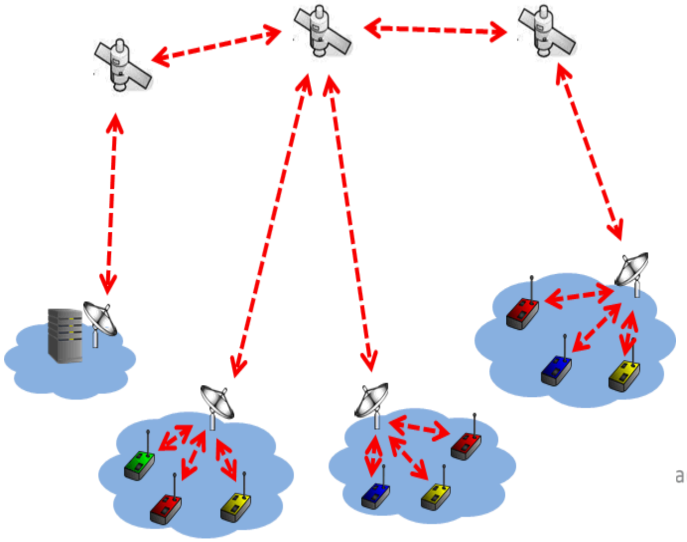
1. Integrated architecture design & optimization
2. Define message sequence diagrams and identify gains achieved with aggregation schemes
3. Data aggregation vs confidentiality
4. Investigate impact of MAC delay on data aggregation
    - Emulated average MAC delay for CRDSA (Contention Resolution Diversity Slotted ALOHA) & ACRDA (Asynchronous Contention Resolution Diversity ALOHA)

M2M/IoT scenarios

1. Synchronous software upgrading of massively deployed IoT nodes
    a. Use case: Over-The-Air (OTA) software and firmware upgrading for IoT devices

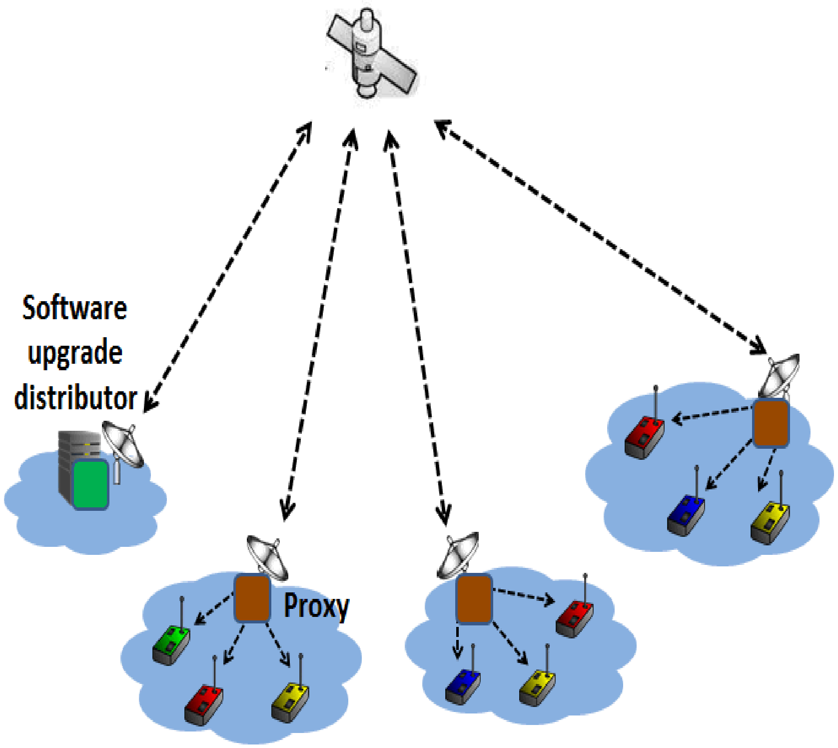


1. Massively connected IoT sensor networks via LEO satellites & hierarchical LEO/MEO/GEO
    a. Use case: Global Sensor Network (GSN) for remote environment observation



Synchronous software upgrading of massively deployed M2M/IoT nodes

1. Different cases:
   a. Common software parts
   b. Partial/differential software upgrading
2. Request model
   a. Non-ICN: single request for whole upgrade
   b. **ICN: request for individual chunks**
3. **Proxy suppresses requests for same chunk**
4. Message overhead depends on
   a. cost for sending request/chunk
   b. percentage of chunks upgraded or common: smaller percentage favors ICN

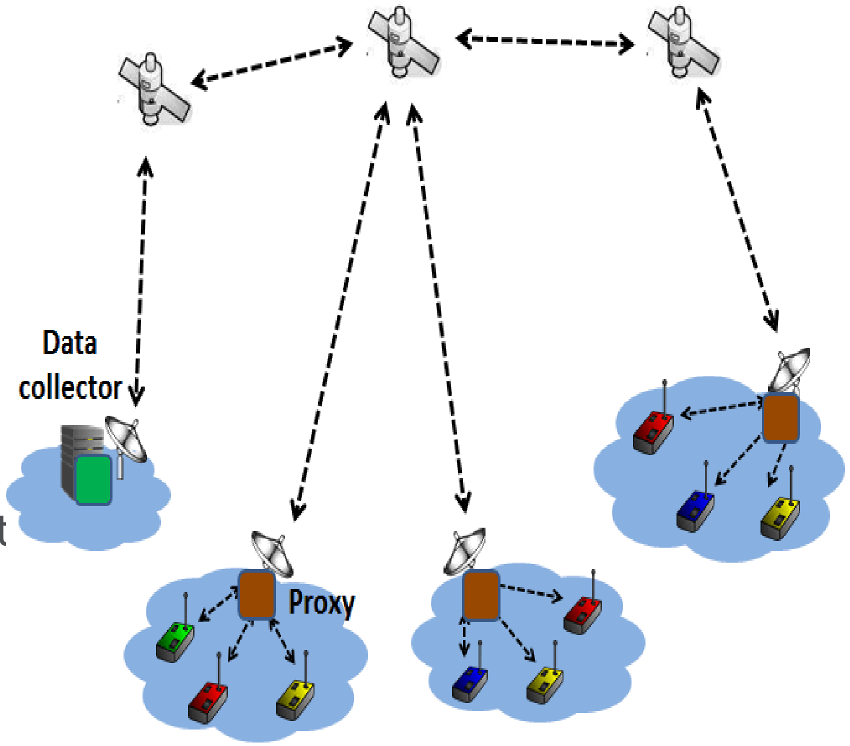


Massively connected IoT sensor networks via LEO satellites

1. Data collector sends requests & receives updates from IoT nodes
2. Subscription proxy:
    a. Proxy polls IoT nodes
    b. Polling over terrestrial network

Two models for data collection:

1. Push: proxy receives sensor updates & forwards to collector
    a. **can perform data aggregation**
2. Pull: proxy notifies collector which request updates from sensors
    a. **Higher confidentiality**



Data aggregation at proxy versus Confidential data transfer

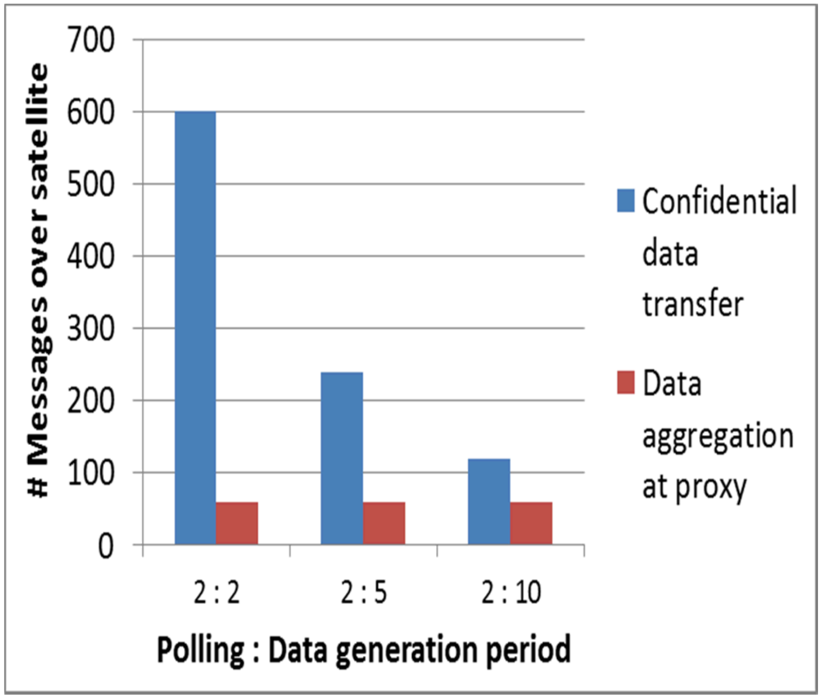
Date aggregation at proxy

1. Proxy polls IoT sensor nodes for updates
    - Polls traverse terrestrial network
2. IoT sensor nodes send data updates to proxy
3. Proxy aggregates updates & periodically sends messages to collector
    - Aggregated data messages traverse satellite
4. Data aggregation: # messages independent of data generation period

Confidential data transfer

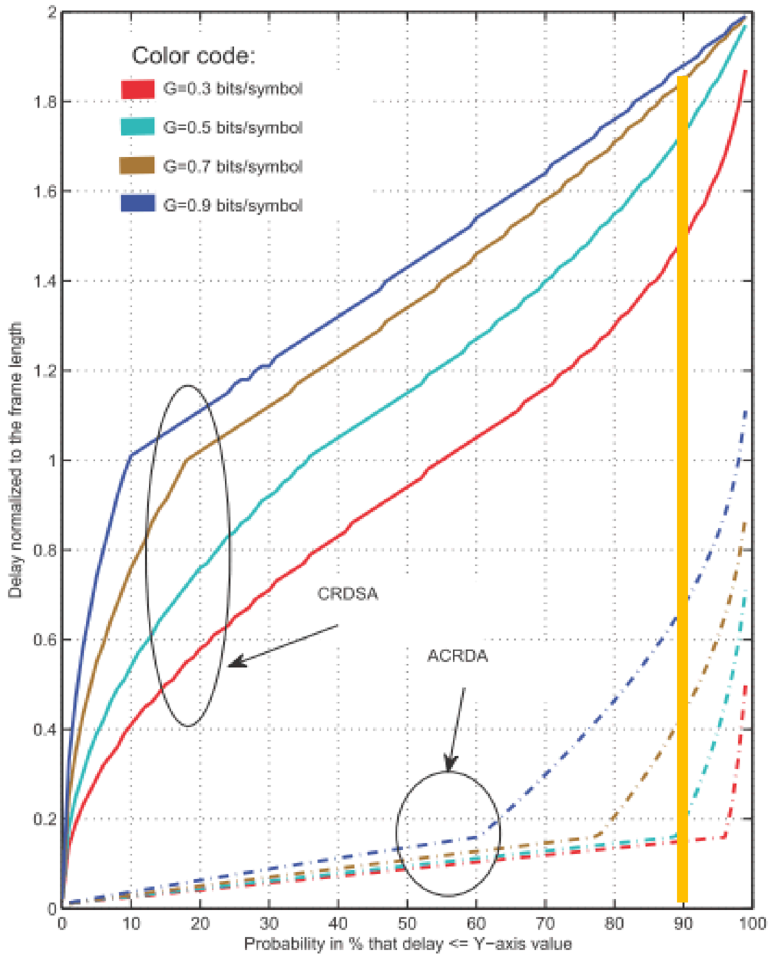
1. Proxy polls IoT sensor node for updates
    - Polls traverse terrestrial network
2. Proxy informs data collector that update exists
3. Collector obtains updates directly from IoT nodes
    - Individual data messages traverse satellite
4. Overhead for confidentiality: higher for smaller data generation period, i.e. more frequent updates

Data aggregation at proxy versus Confidential data transfer



1. Data aggregation: # messages independent of data generation period
2. Overhead for confidentiality: higher for smaller data generation period, i.e. more frequent updates

IoT sensor network with data aggregation: influence of MAC delay

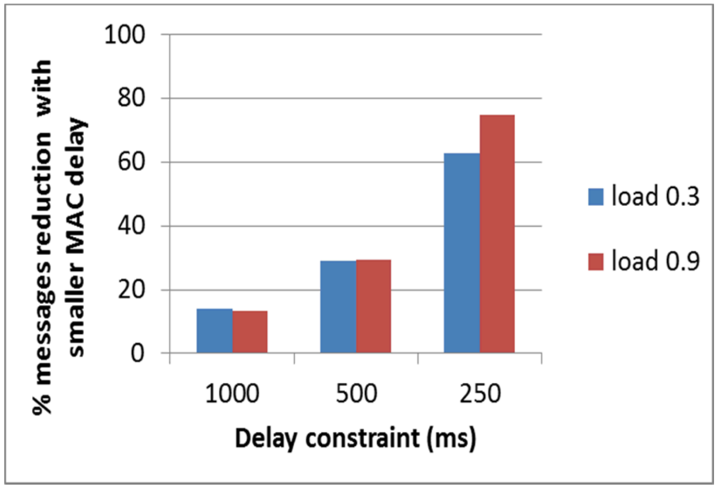


R. D. Gaudenzi, et al., “Asynchronous Contention Resolution Diversity ALOHA: Making CRDSA Truly Asynchronous,” IEEE Trans. Wireless Commun., July 2014

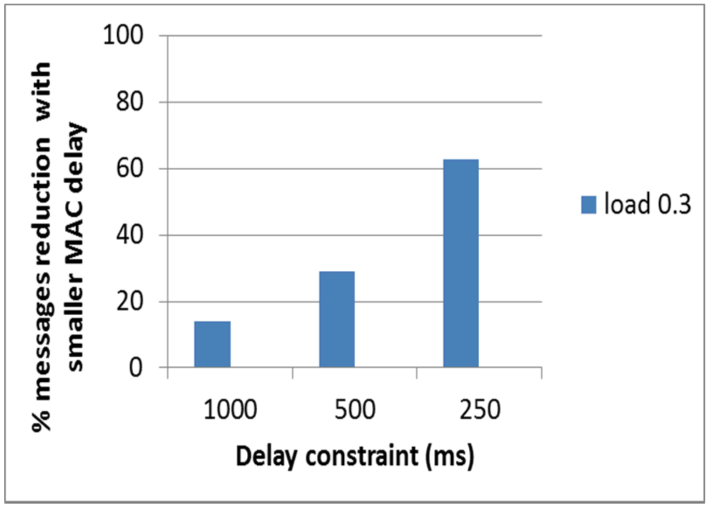
1. **CRDSA vs ACRDA**
2. 90% percentile delay (normalized to frame length) for **load 0.3** bits/symbol:
    a. CRDSA: 1.5, ACRDA: 0.15
    b. **10 fold reduction**
3. **Emulated delay:**
    a. For 100 ms frame length, CRDSA: 150 ms, ACRDA: 15 ms
    b. LEO delay: 20ms
4. **Load 0.9** bits/symbol:
    a. CRDSA: 190 ms, ACRDA: 70 ms
    b. **2.7 reduction**

IoT network with data aggregation: influence of MAC delay

1. MAC delay (message delay in general) does not influence signaling aggregation
    1. Proxy caches subscription requests
    2. Proxy suppresses subscription requests for same content
2. MAC delay (message delay in general) influences data aggregation only for scenarios with delay constraints
    1. E.g. maximum delay for data to reach collector



- 1000,500 ms: smaller MAC delay gains same for load 0.3, 0.9
- 250 ms (tighter constraint): smaller MAC delay has higher gain for larger load



Smaller delay constraint ⇒
higher gain with smaller MAC delay

Conclusions

1. Application of ICN for integrated satellite-terrestrial networks can have significant gains for IoT scenarios:
    a. Synchronous software upgrading
    b. Interconnection of IoT sensor networks
2. ICN-satellite testbed investigations illustrated
    a. Significant improvements with signal/data aggregation
    b. MAC delay
        - does not impact signal aggregation
        - impacts data aggregation only when there are delay constraints

Way forward

1. Follow on investigation of simple tunable protocols based on E-SSA and ACDRA to jointly boost the system performance –achieve high thoughput and keep the energy expenditure low.**
2. Need to further harmonise satellite and terrestrial MAC for M2M/IoT
3. Need for a large scale integrated satellite-terrestrial 5G M2M/IoT demonstrator
    - To support differentiation of broad range of IoT services based on valued added ‘big data from the space’ [GPS/GNSS, environmental data, and other sensor data] for different verticals
    - To verify MAC and networking concepts and feasibility of end-to-end integrated solutions
4. Willing to contribute to 5G Architecture Whitepaper on concepts related to the Massive IoT use case covering satellite component

And

Thanking all our teams !!!

*** Proceedings ICC 2016: ‘Spreading and Repetitions in Satellite MAC Protocols’, Alessandro Biason, Andrea Dittadi and Michele Zorzi*