6G Wireless Summit
Levi, Finland, March 26th 2019

From 5G to 6G: Has the Time for Modern Random Access Come?

Federico Clazzer[†], Andrea Munari[†], Gianluigi Liva[†], Francisco Lazaro[†],
Cedomir Stefanovic[‡], Petar Popovski[‡]
federico.clazzer@dlr.de

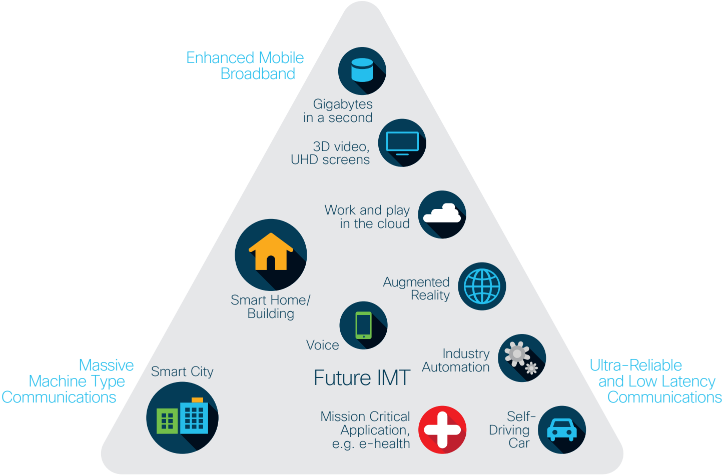
[†]Institute for Communications and Navigation
German Aerospace Center, DLR

[‡]Department of Electronic Systems
Aalborg University

Outline

1. 5G and IoT Traffic
2. Inefficiencies of Classic Communication Solutions
3. Modern Random Access
4. Modern Random Access for Beyond 5G

5G use cases


Enhanced Mobile Broadband
Gigabytes in a second
3D video, UHD screens
Work and play in the cloud
Smart Home/ Building
Augmented Reality
Voice
Industry Automation
Massive Machine Type Communications
Smart City
Future IMT
Ultra-Reliable and Low Latency Communications
Mission Critical Application, e.g. e-health
Self-Driving Car

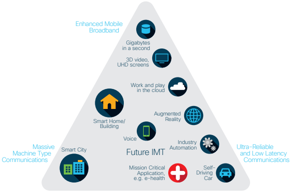
5G mMTC and URLLC requirements

- Massive machine type communications (mMTC) target huge and very dense transmitter populations
  - >10k transmitters per base station
  - >1M transmitters per square kilometer.

  push for very high throughput/spectral efficiency.

- Ultra reliable low latency communications (URLLC) collect all use cases where very high reliability and/or low latency is required
  - transmission success $>99.999\%$
  - latency as low as 1 ms.

  push for very low packet error rate.



IoT traffic characteristics

A change of perspective

- Transmitters generate small data packets
- in a sporadic and sometimes unpredictable manner.
- The data channel is shared among a vast population.

Key issue: identify an efficient and flexible policy for the medium access.

Scheduled access

How overhead becomes an issue

- Scheduled access, e.g. TDMA, is efficient when single transmitters generate (sufficiently) large data packets in a predictable fashion.
- It normally requires a central entity to assign orthogonal resources to the transmitters, i.e. avoiding interference.
- When the data traffic is sporadic, the assignment has to be updated more frequently.
- When the data traffic features small data, the amount of overhead required to update the schedule becomes comparable to the data traffic.[1]

Key issue: overhead limits the efficiency of scheduled access in IoT scenarios.

[1] G. C. Madueo, J. J. Nielsen, D. M. Kim, N. K. Pratas, C. Stefanovic, and P. Popovski, "Assessment of LTE Wireless Access for Monitoring of Energy Distribution in the Smart Grid," *IEEE J. Sel. Areas Commun.*, vol. 34, no. 3, 2016.

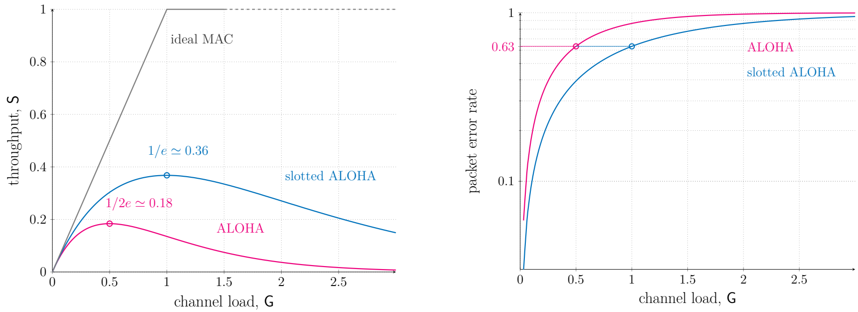
Random access

Current approaches

- Random access appears as a natural solution for shared medium access
  - nodes transmit in an uncoordinated fashion
  - grant-free access: no overhead for resource allocation
- LTE and 5G already resort to random access for logon and resource requests procedures (PRACH)
  - with early data transmission (EDT), possibility to piggyback data.
- Commercial IoT solutions, e.g. LoRaWAN and Sigfox implement variations of ALOHA.
- Interest in using random access for data transmission, yet performance of traditional schemes does not meet mMTC nor URLLC requirements.

Random access (for data transmission)

Low reliability and low throughput



Key issue: low reliability and low throughput.

Modern random access

A second youth for ALOHA

- The key idea of modern random access is to constructively embrace interference.
- Transmitters send multiple copies of their packets.
- At the receiver successive interference cancellation (SIC) is performed.
- First example was contention resolution diversity slotted ALOHA (CRDSA).[2]
- Extended by the coded slotted ALOHA (CSA) protocols.[3]

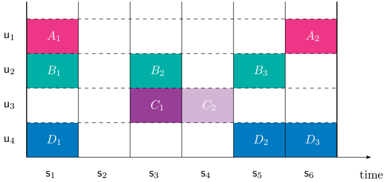
---

[2] E. Casini, R. de Gaudenzi and O. del Rio Herrero, "Contention Resolution Diversity Slotted ALOHA (CRDSA): An Enhanced Random Access Scheme for Satellite Access Packet Networks", *IEEE Trans. on Wireless Comm.*, vol.6, No.4, 2007.

[3] E. Paolini, G. Liva and M. Chiani, "Coded Slotted ALOHA: A Graph-Based Method for Uncoordinated Multiple Access", *IEEE Trans. on Inf. Theory*, vol.61, No.12, 2015.

Transmissions according to CSA

- Transmissions are organized into frames composed by a fixed number of time slots.
- Users becoming active in a given frame, will transmit in the subsequent.
- User 1 transmits two replicas.
- User 2 transmits three replicas.
- User 3 transmits two replicas.
- User 4 transmits three replicas.

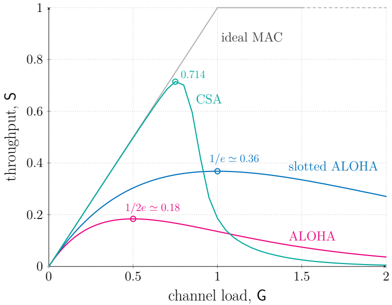


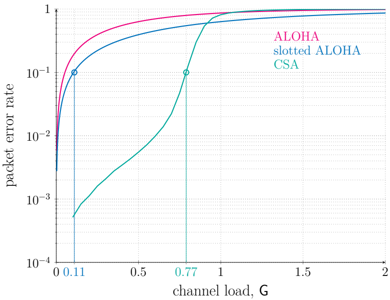
SIC in CSA

- The receiver buffers the whole frame and starts decoding by looking for interference-free packets.
- User 3 second replica is free from interference and is decoded first.
- Its interference and the interference of its twin is removed.
- Freeing from interference user 2 second replica.
- Iterating the process, we are able to retrieve all data packets.

DLR

Performance of CSA





Variations of modern random access

- Enhanced spread spectrum ALOHA,[4]
- Frameless ALOHA,[5]
- Frame-asynchronous CSA,[6]
- Enhanced contention resolution ALOHA.[7]

---

[4] O. del Rio Herrero and R. De Gaudenzi, "High Efficiency Satellite Multiple Access Scheme for Machine-to-Machine Communications," *IEEE Trans. Aerosp. Electron. Syst.*, vol. 48, no. 4, 2012.

[5] C. Stefanovic and P. Popovski, "ALOHA Random Access that Operates as a Rateless Code," *IEEE Trans. Commun.*, vol. 61, no. 11, 2013.

[6] E. Sandgren, A. Graell i Amat, and F. Brannstrom, "On Frame Asynchronous Coded Slotted ALOHA: Asymptotic, Finite Length, and Delay Analysis," *IEEE Trans. Commun.*, vol. 65, no. 2, 2017.

[7] F. Clazzer, C. Kissling, and M. Marchese, "Enhancing Contention Resolution ALOHA using Combining Techniques," *IEEE Trans. Commun.*, vol. 66, no. 6, 2018.

Modern random access for beyond 5G

Potential

- Modern random access can bring important performance gains for IoT.
- CSA and other modern random access protocols are already included in satellite communication standards.
  - ETSI DVB-RCS2 (satellite return link standard)
  - S-MIM (S-band mobile interactive multimedia standard).
- Current LTE and 5G solutions not relying on random access for data transmission.
- Modern random access can help fulfill mMTC and URLLC requirements beyond 5G.

Modern random access for beyond 5G

Challenges

- Synergies and interactions with 5G techniques, e.g. OFDM, massive MIMO, NOMA, . . . , still unexplored.
- Specific traffic patterns of industrial IoT have to be considered
  - e.g. (partial) correlation among transmitter activity.
- Terrestrial channel characteristics have to be included in the medium access design.
- Combinations of modern random access and NB-IoT shall be considered.

Thank you for your attention!