Aalto University
School of Science

In-device coexistence simulations for smartphones

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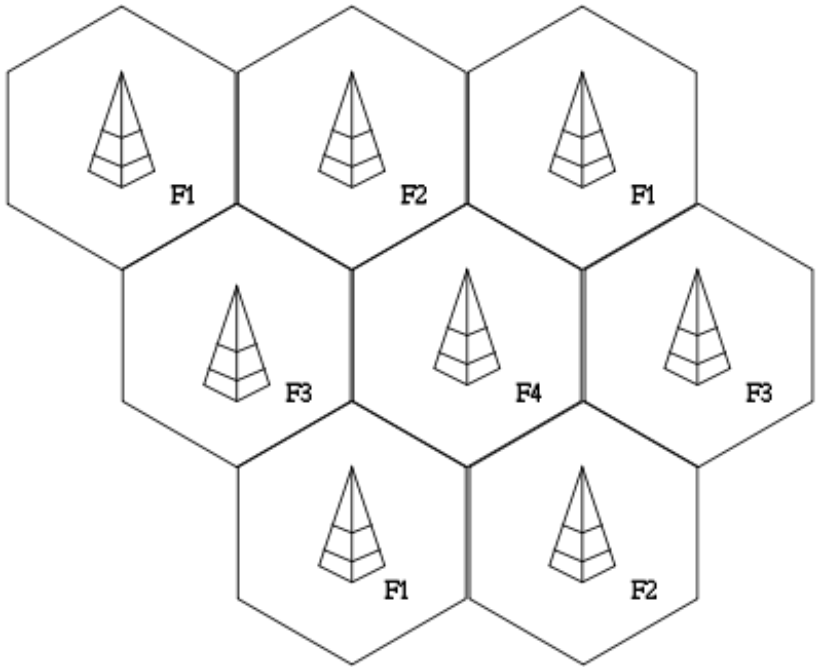
Outline

- Cellular radio systems and radio devices
  - Mobile devices and their subsystems
  - Radio bands, transmission and radio coexistence
- Simulation coexistence
  - Supporting simulations of complex protocols and hardware
  - Embedding a simulator into a host language
- Some results
  - Focusing on LTE and WiFi coexistence
  - Managing radio coexistence opens up new opportunities

Cellular networks

- Base stations
  - Forming cells
  - Hexagonal in principle
    - The practice is somewhat different
- Mobile devices
  - Connect to base stations
- The network
  - Keeps track who is where
- Protocols
  - Large number of protocols
  - Several generations of systems: from GSM to LTE
- Coexistence
  - Add other radio systems

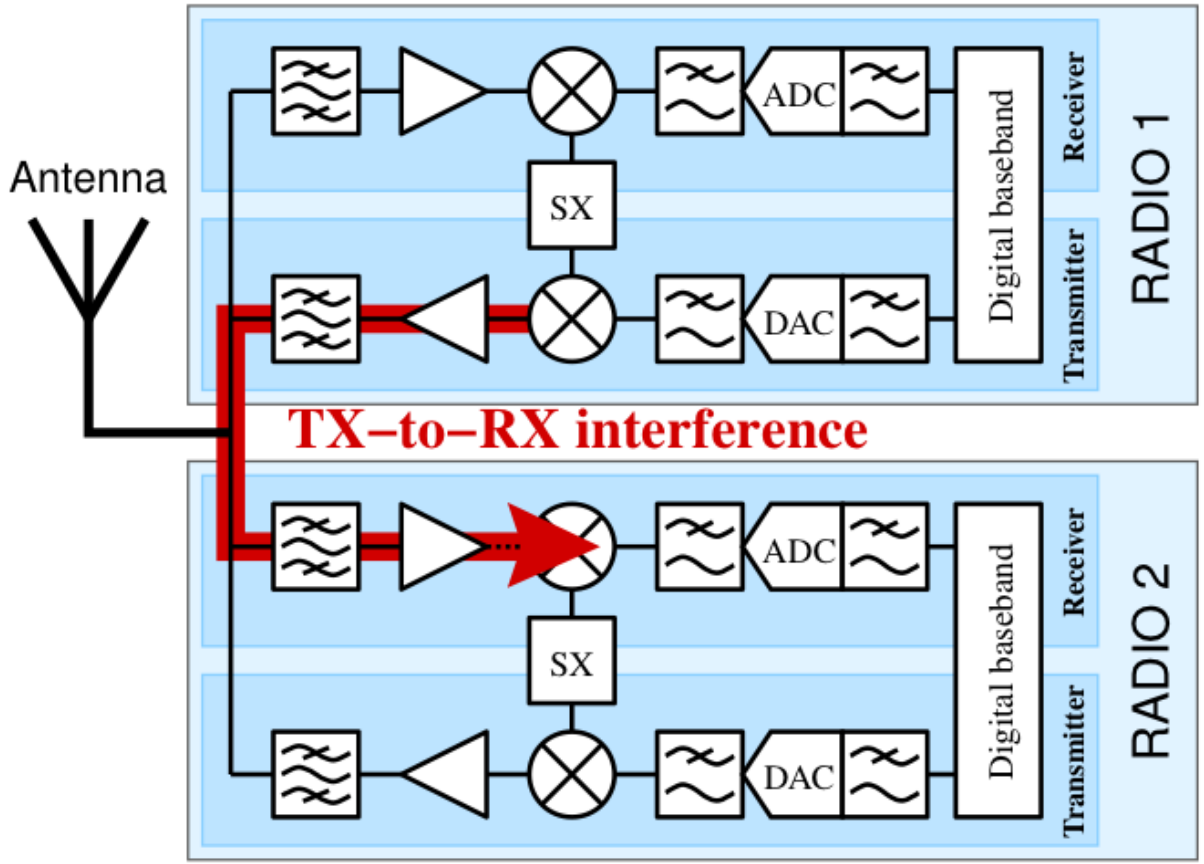


Mobile devices

- Small devices
  - Battery operated
    - Energy consumption is important
  - Include numerous subsystems
    - Balanced operation needed
- Connectivity is essential
  - Mostly based on radios
  - Several radios
    - GSM/LTE, WiFi, Bluetooth, GPS, NFC, ..
- Coexistence
  - Radios interfere with each other
    - In the air
    - Inside the devices
  - Basic ways to avoid
    - Time domain, frequency domain

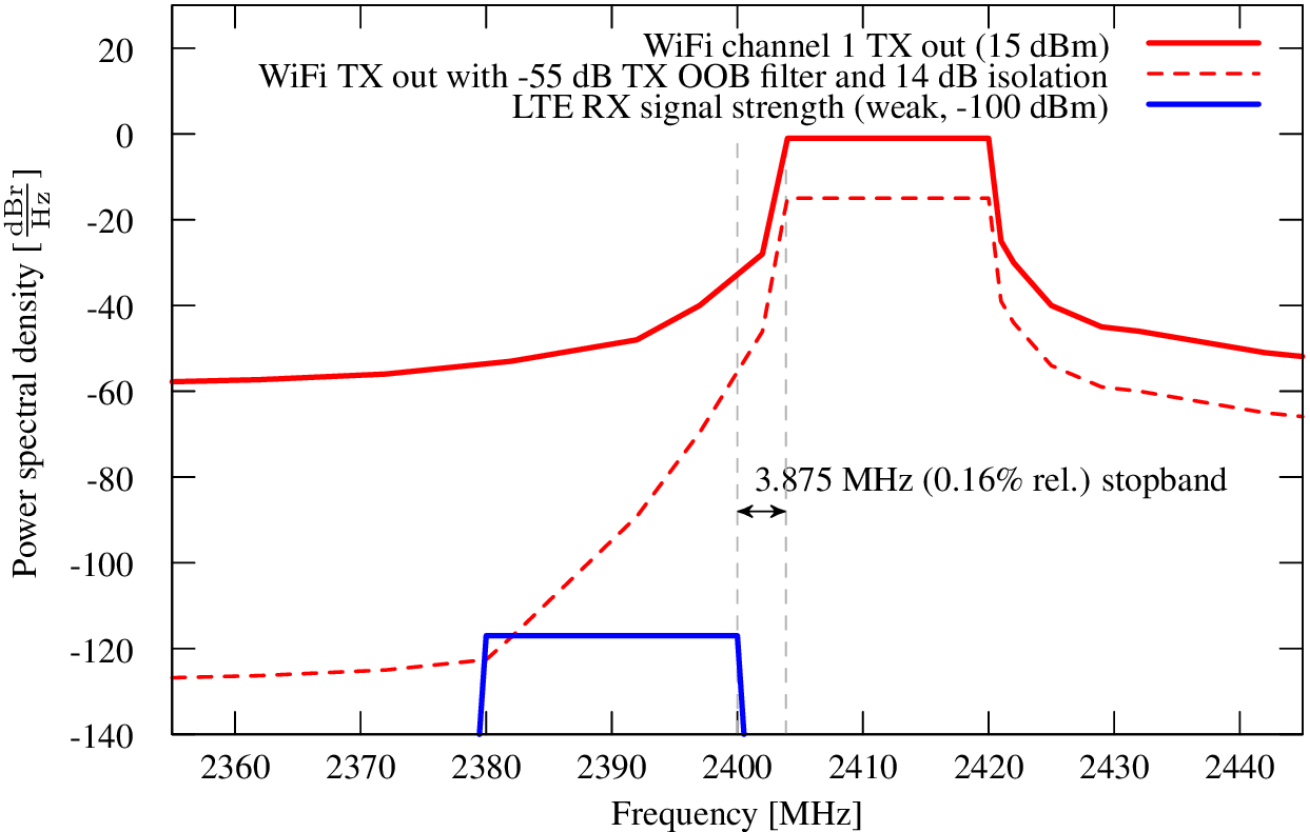
Radio device

- Receivers and transmitters



Spectrum usage

- Transmitter power exceeds significantly the reception



Simulation of coexistence (requirements)

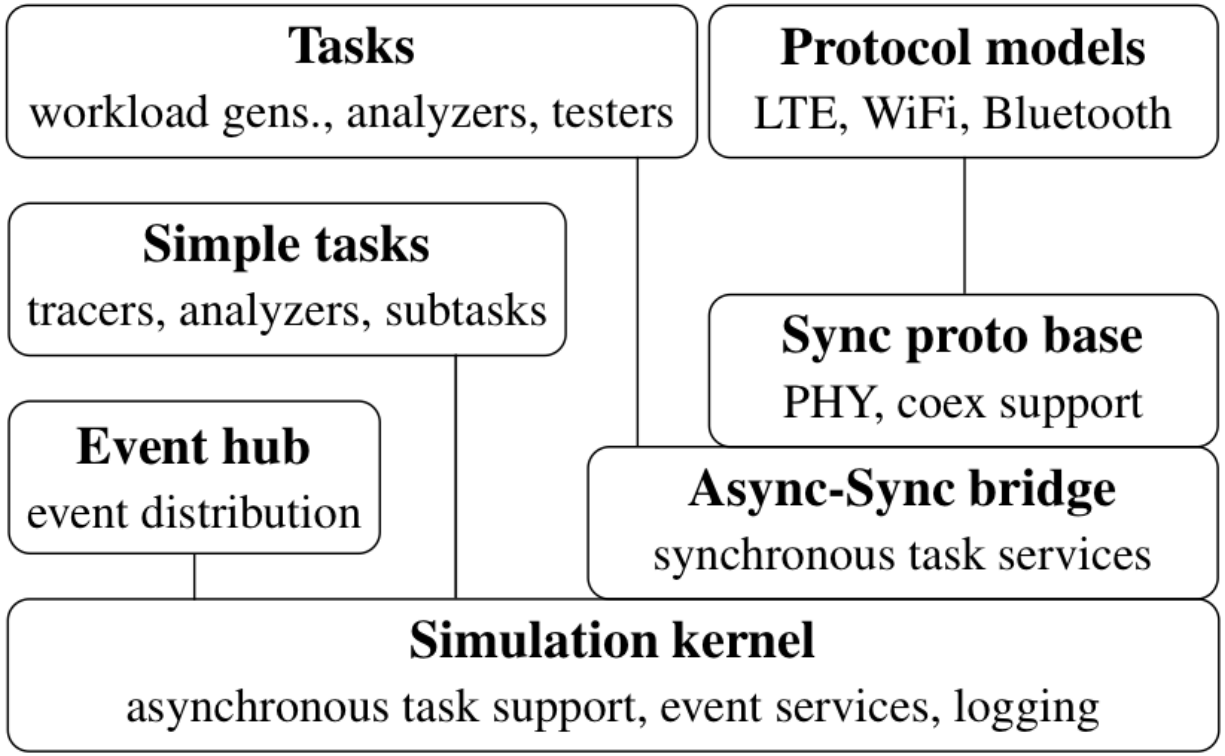
- Several different aspects to be covered
  - On-chip software manages the chip
  - Discussion between the hardware and protocols
    - Especially the MAC level of protocols
- Physical side not so complex
  - However, RF chips not trivial
    - We used a RF-CGRA design
  - Resource management to be simulated
- Protocols managing the coexistence are complex
  - Must be simulated in detail, but real implementations are huge
  - Scheduling in time domain – real traffic but with < 1µs details
- Real-time
  - Both synchronous and asynchronous events

Simulation of coexistence (our solution)

- Embedding the simulator inside a programming language to ensure programmability
  - Supporting different types of tasks
  - Basic facilities for radio simulation
- Modeling is the challenge
  - Like a learning project: how to delimit and abstract
- The resulting model
  - Textual representation
    - Using a programming language (Java based)
  - Roughly 20000 lines of model description
- Validation and verification
  - Especially for protocol and hardware development

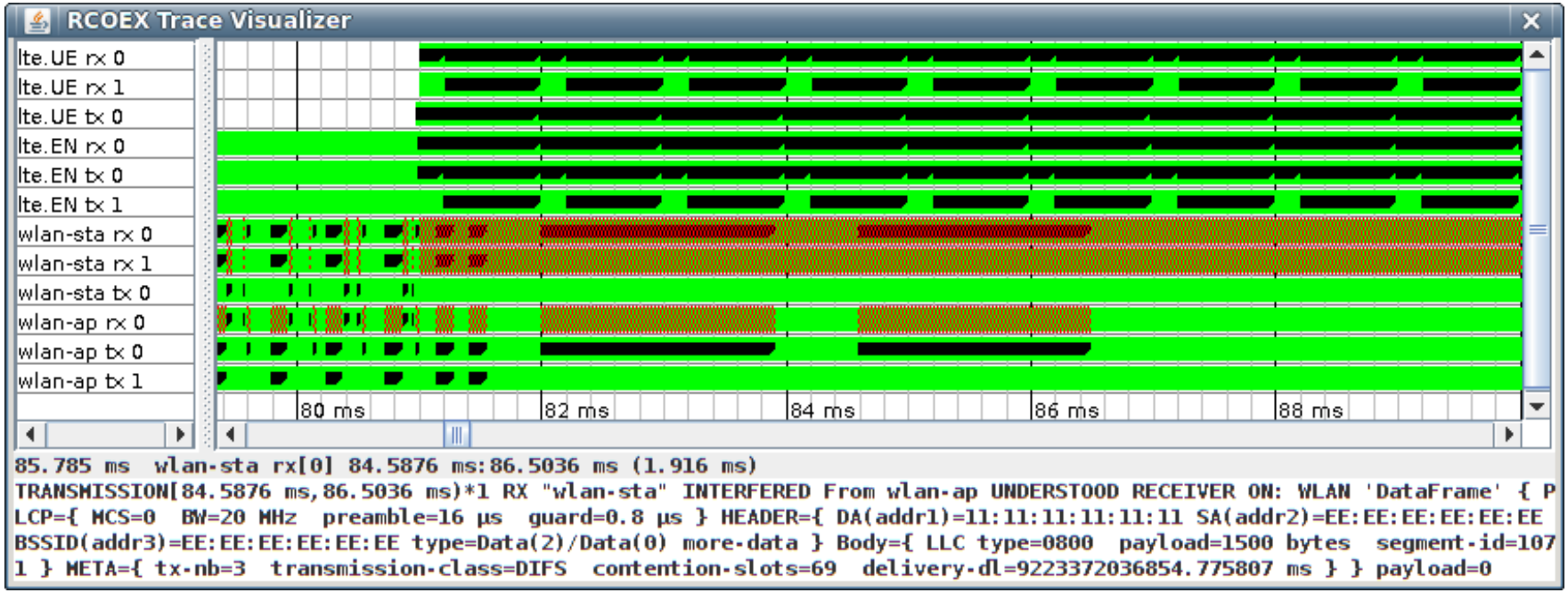
Simulator structure

- Built on top of a simulation kernel



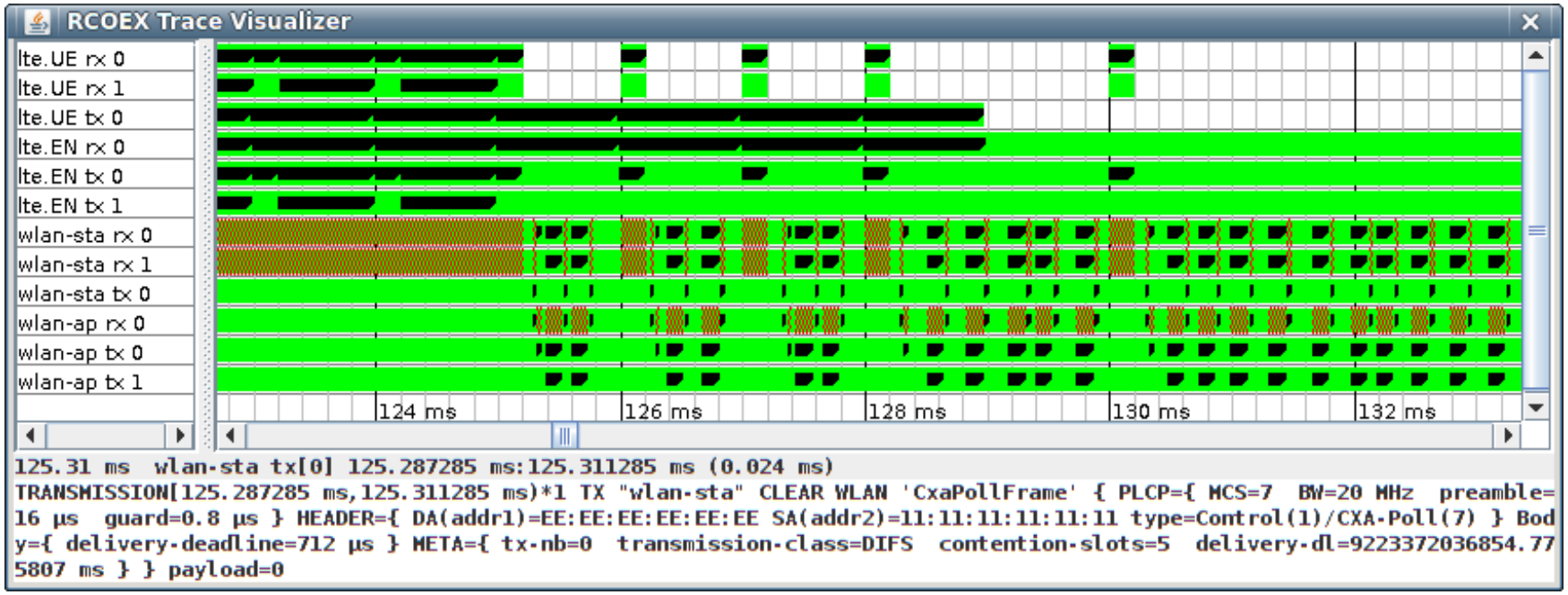
Simulator user interface

- Gives detailed information of events
  - Graphical representation
  - Using pointer to get more information



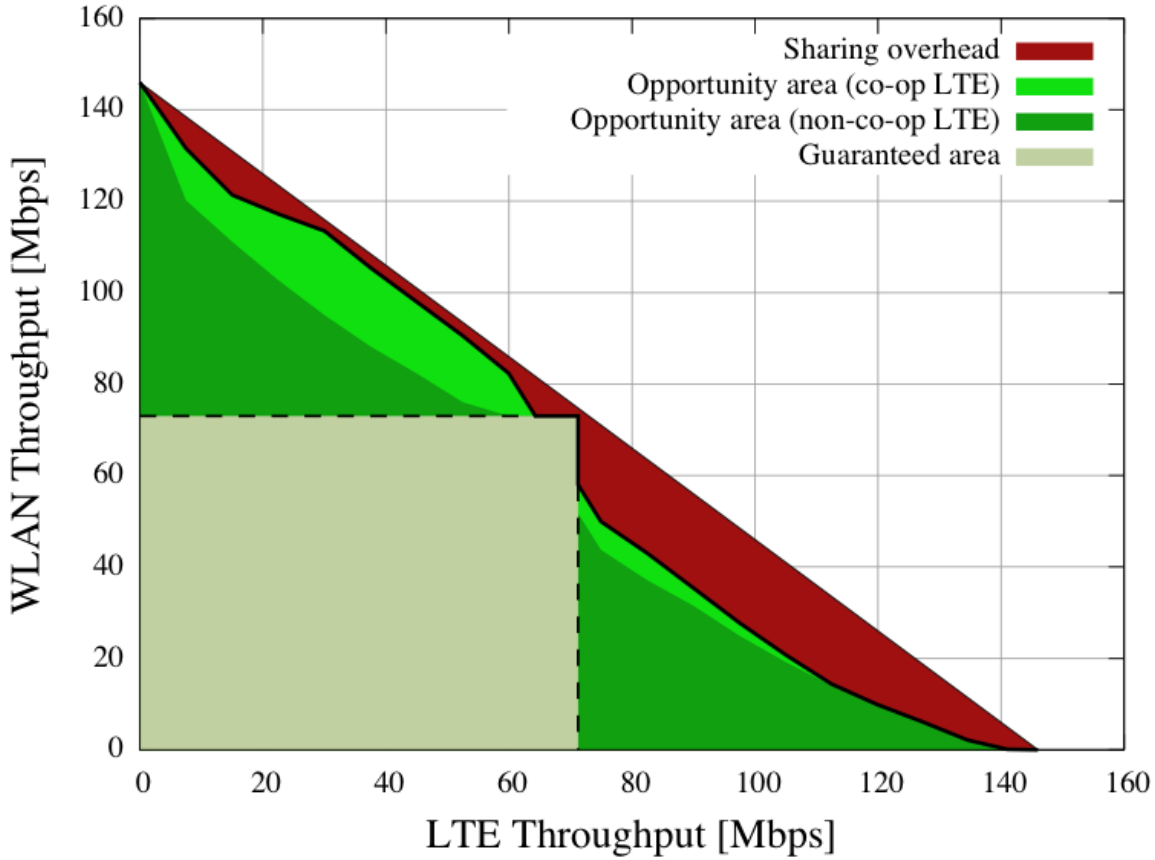
Simulator user interface

- Studying the operation
  - Finding out the causes for bad behavior
  - Modifying the protocol(s) results in significant improvements



Coexistence benefits

- Managed coexistence significantly increases throughput



Conclusions

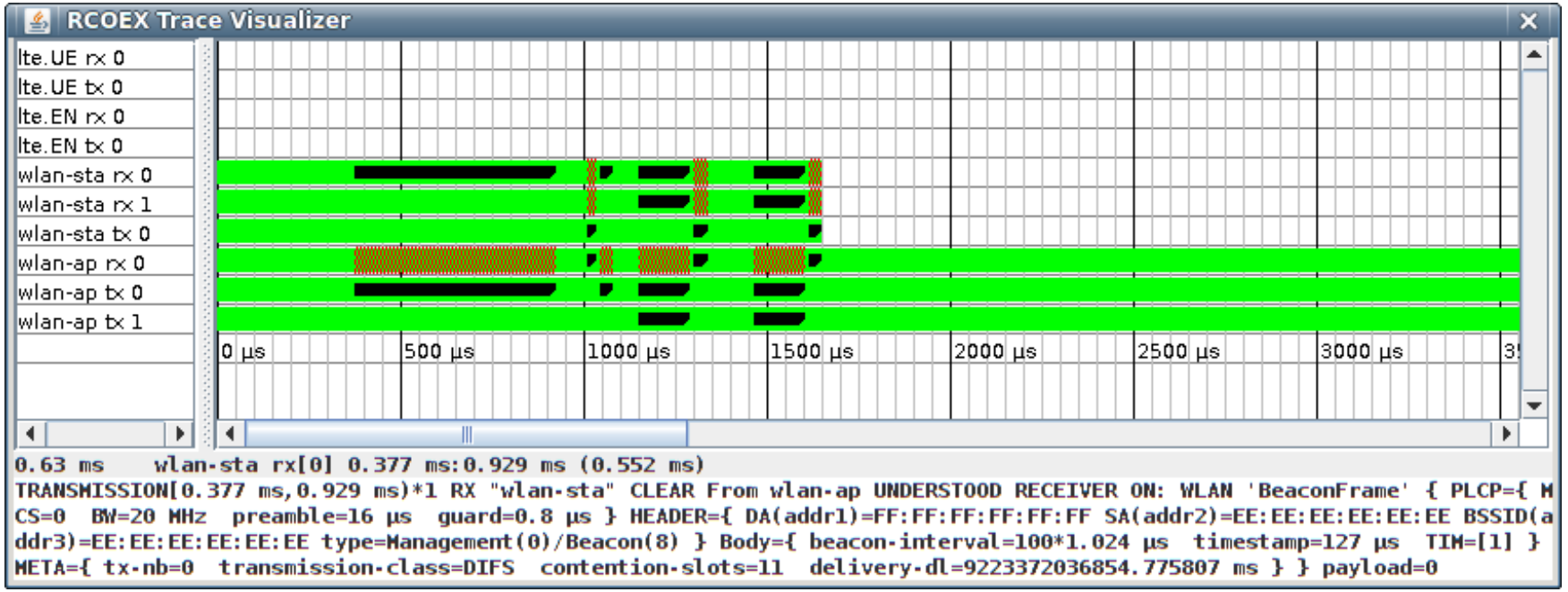
- Radio coexistence simulation
  - Coping with complex protocols and hardware is essential
- In-device coexistence
  - Radios interfere with each other
  - Basic solution is to have only one radio on
    - The problem is in predictability
- Managing radio coexistence opens up new opportunities
  - We focused on LTE and WiFi coexistence
  - U-APSD based mechanism for coexistence
    - Predicting radio traffic
    - Reserving time for the competing radio
- Research on simulation techniques needed
  - Large systems mixing different kinds of operation

Thank you!

Extra slides

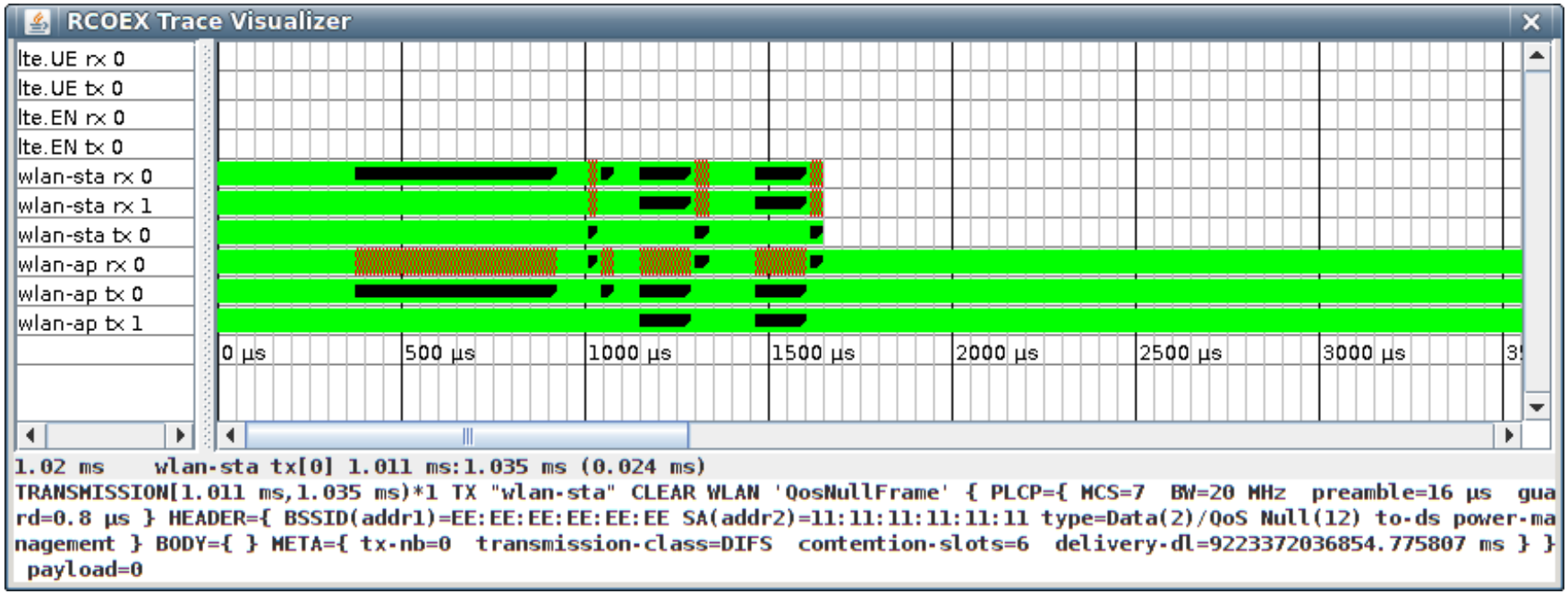
Simulating WiFi (1)

- Beacon



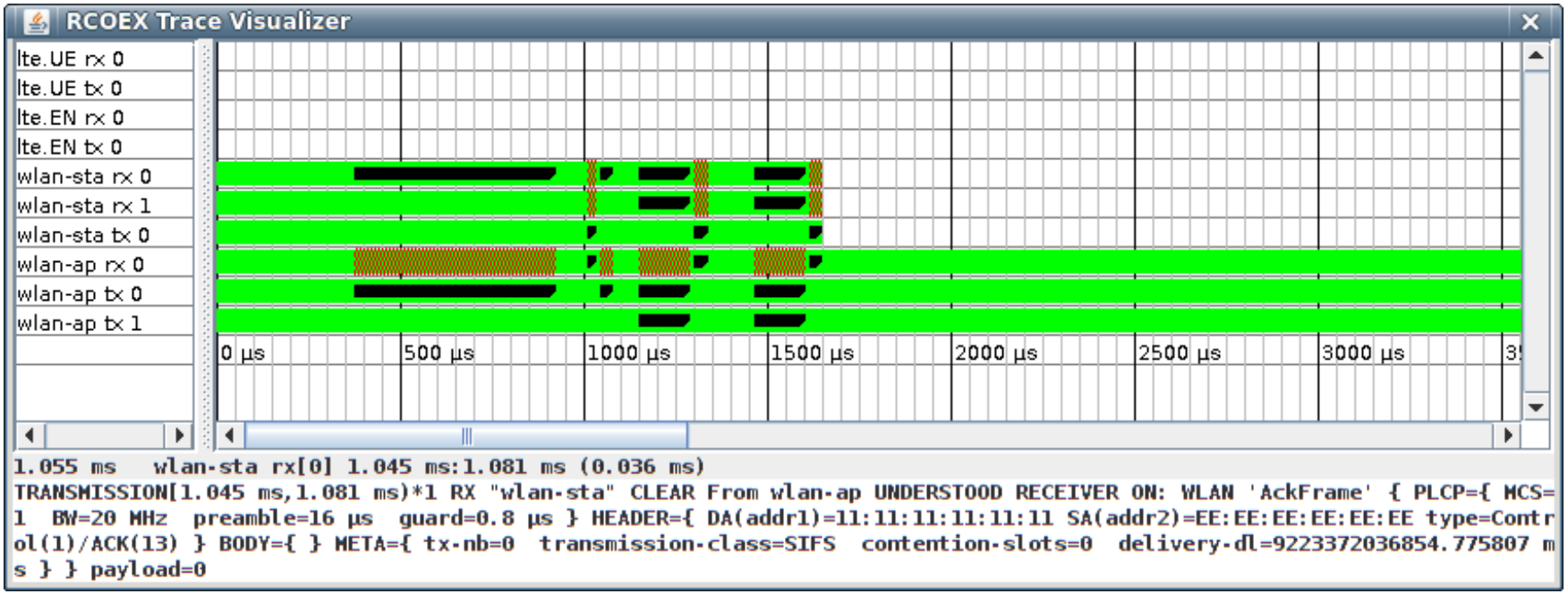
Simulating WiFi (2)

- UAPSD - trigger



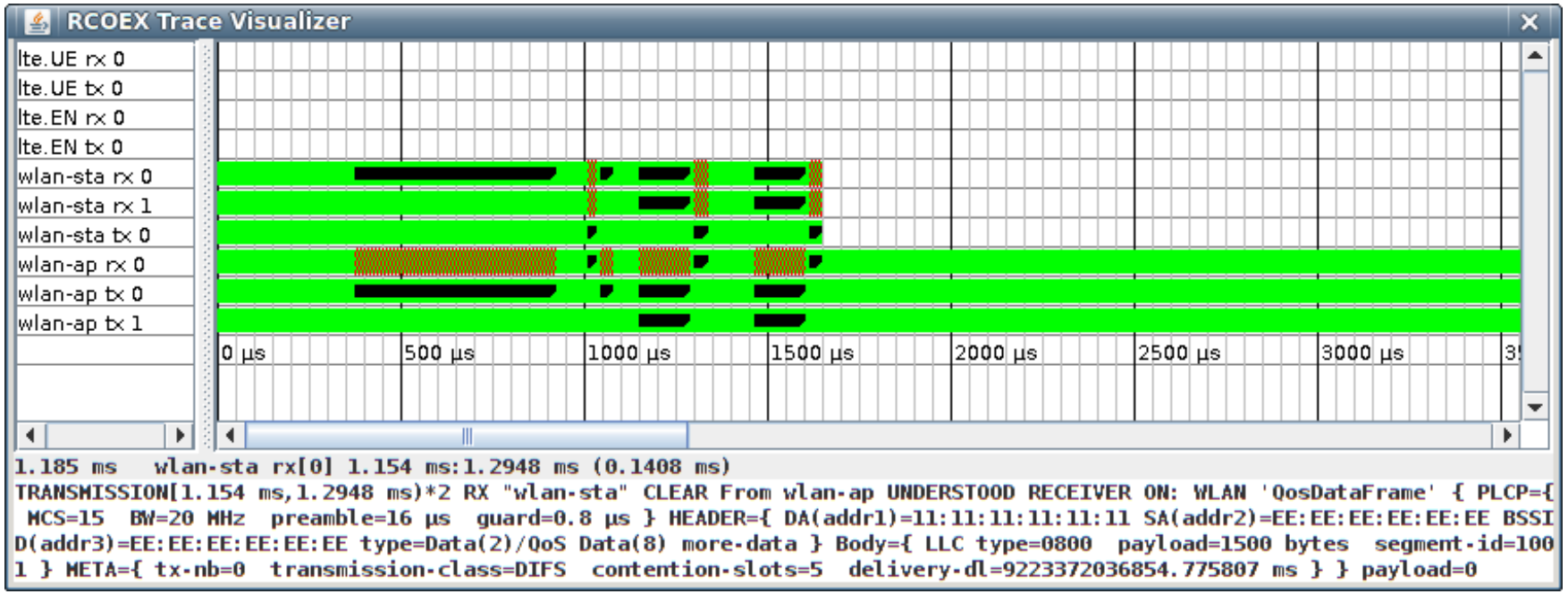
Simulating WiFi (3)

- Trigger ackn



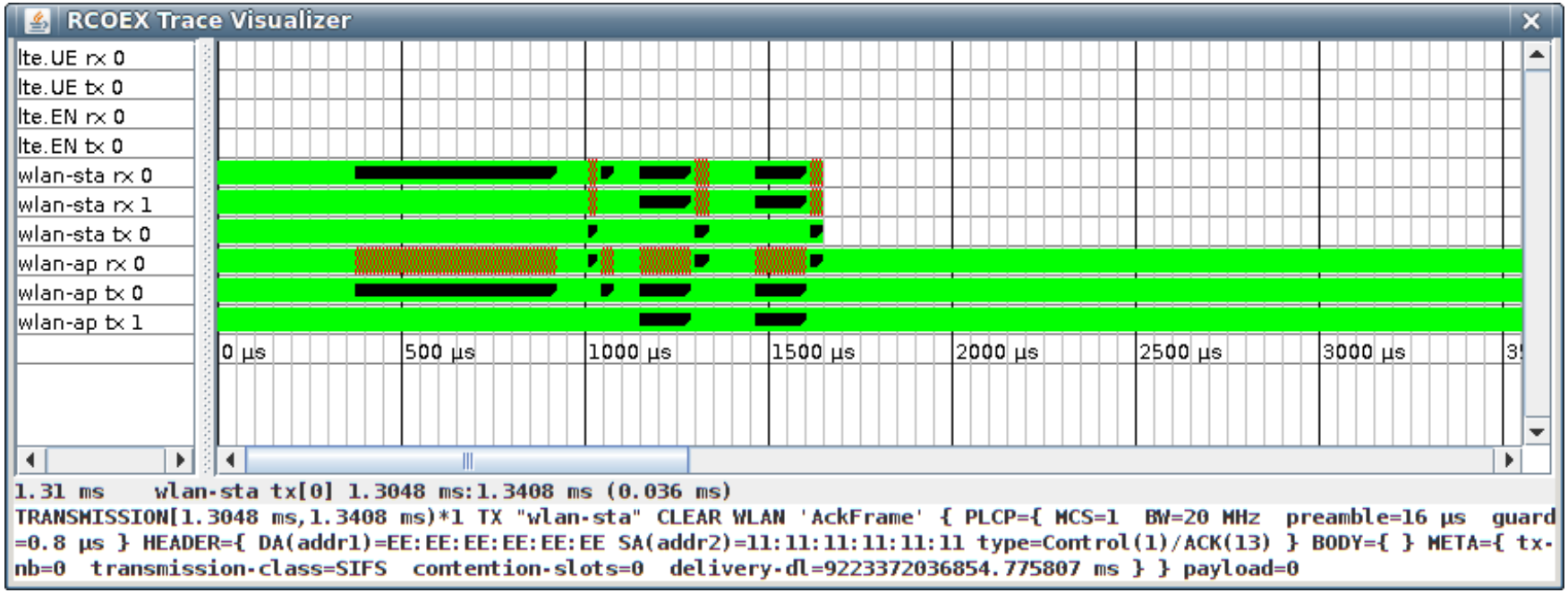
Simulating WiFi (4)

- Data



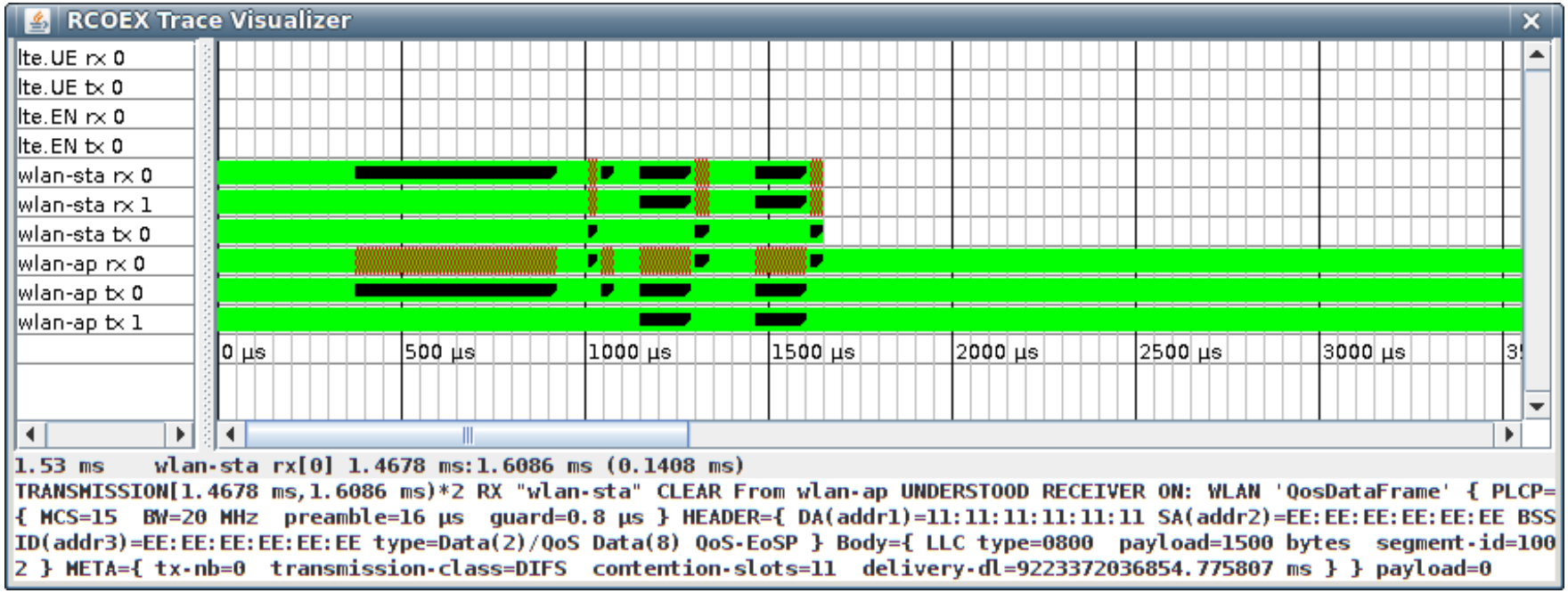
Simulating WiFi (5)

- First ackn



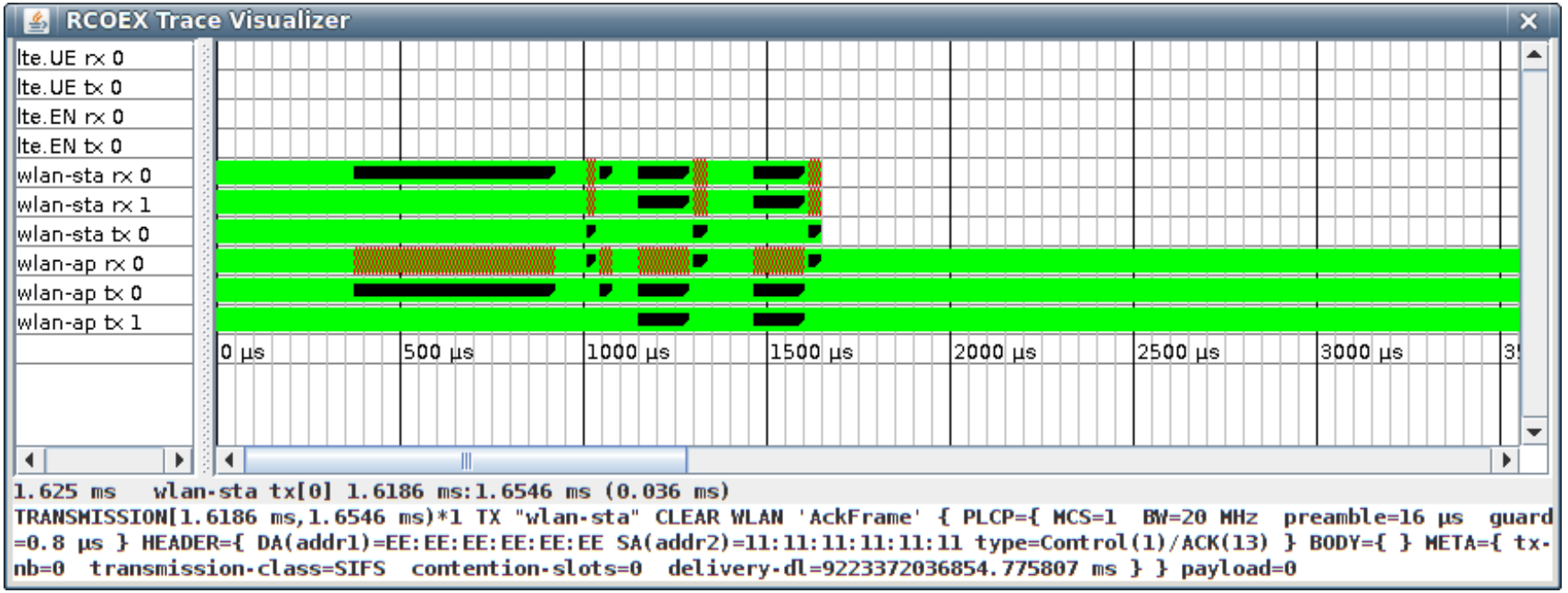
Simulating WiFi (6)

- Second data



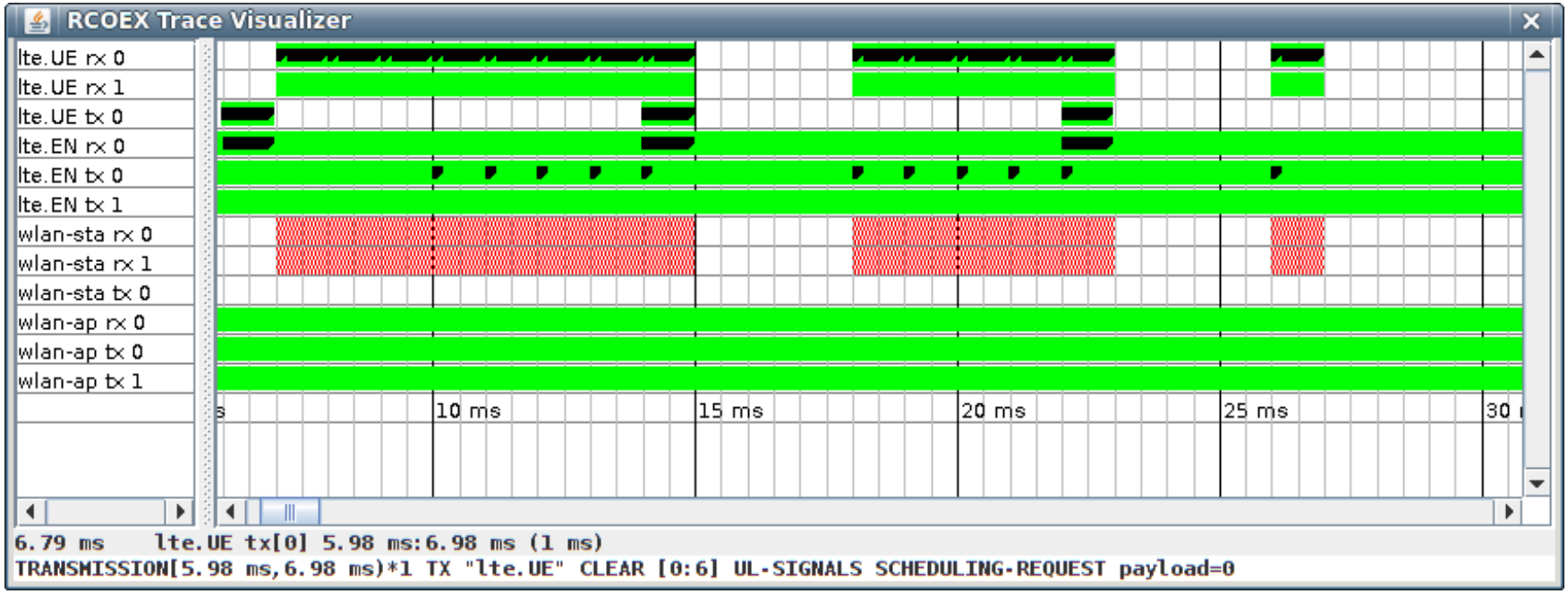
Simulating WiFi (7)

- Second ackn



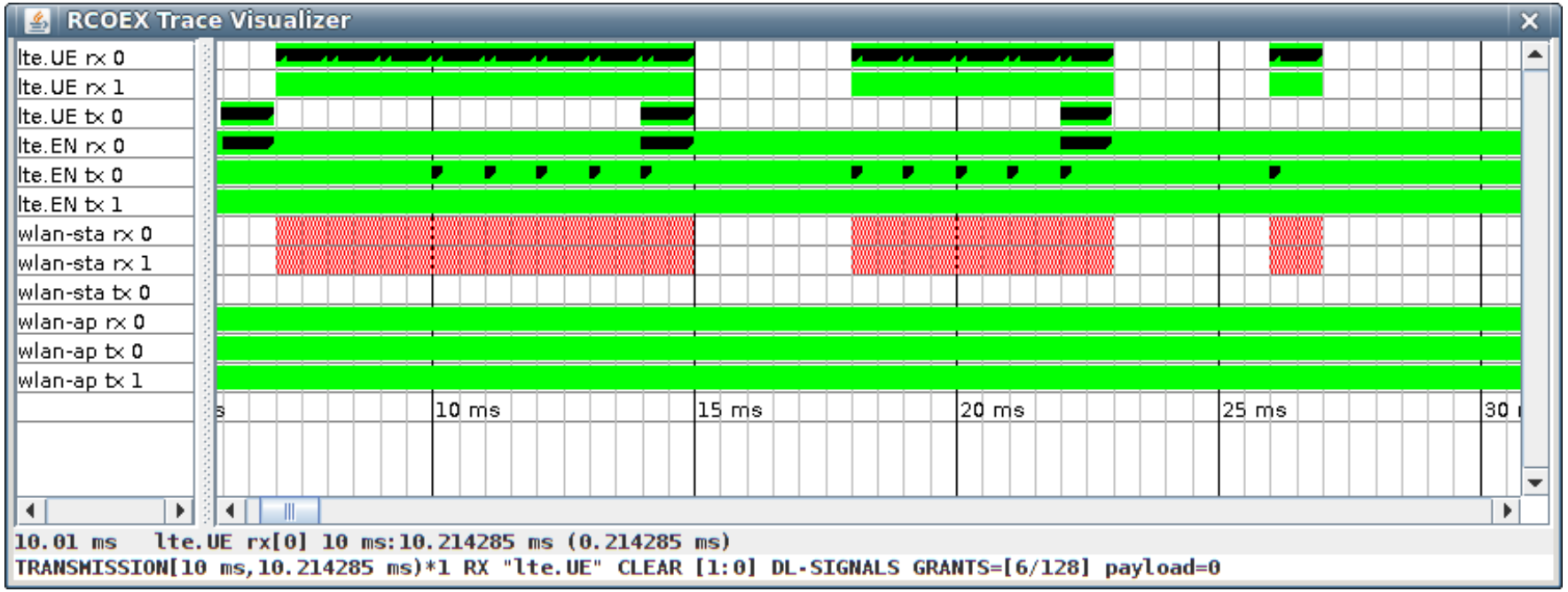
Simulating LTE (1)

- Scheduling request



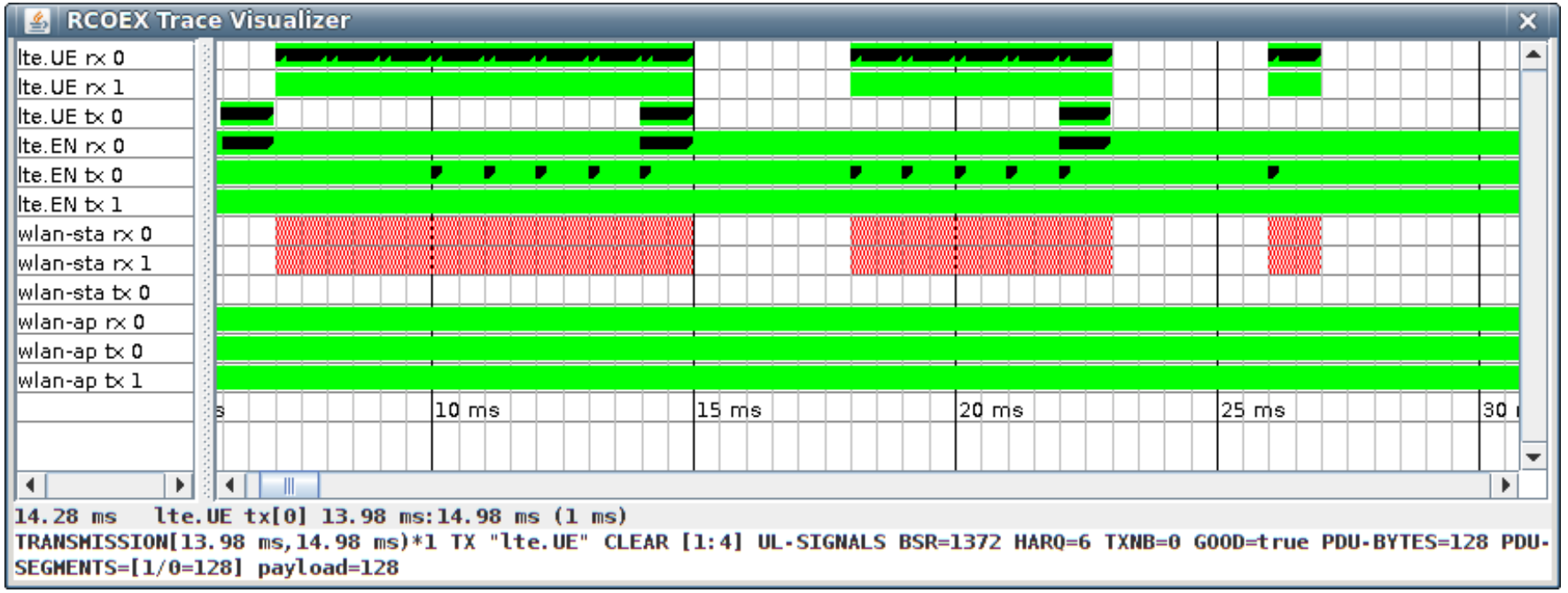
Simulating LTE (2)

- Uplink grant



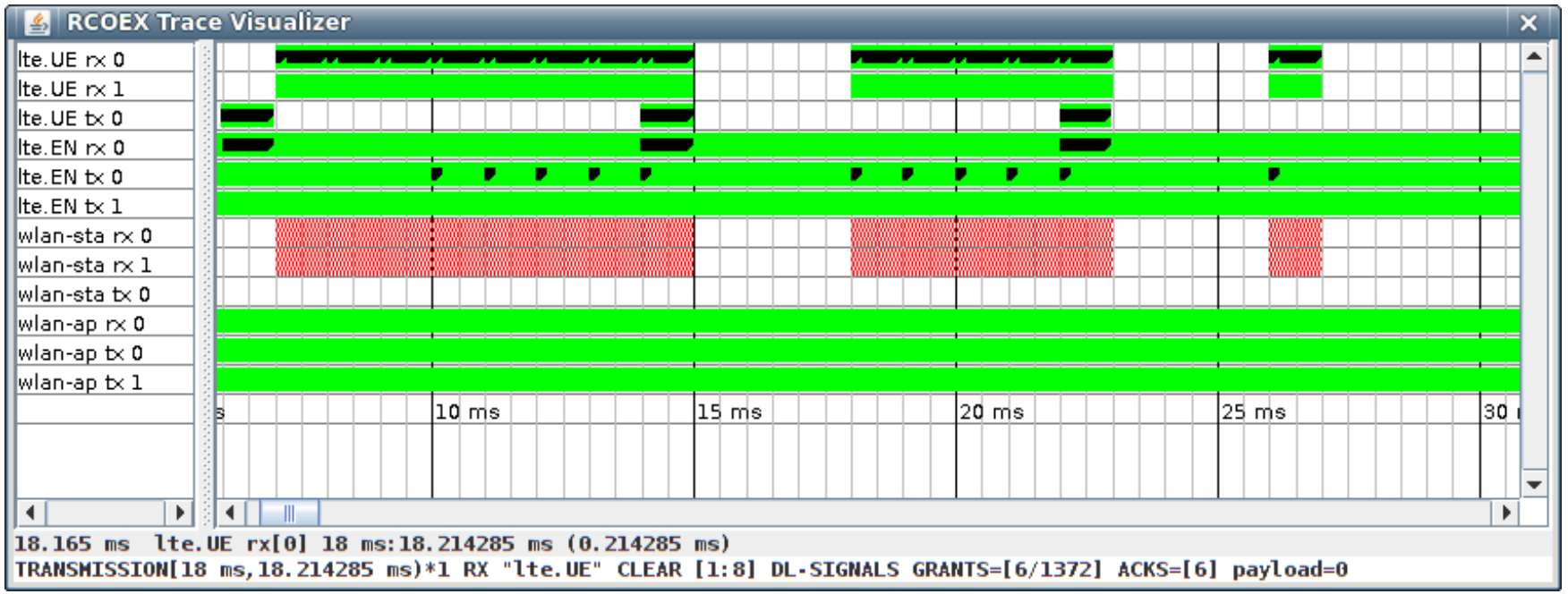
Simulating LTE (3)

- First data



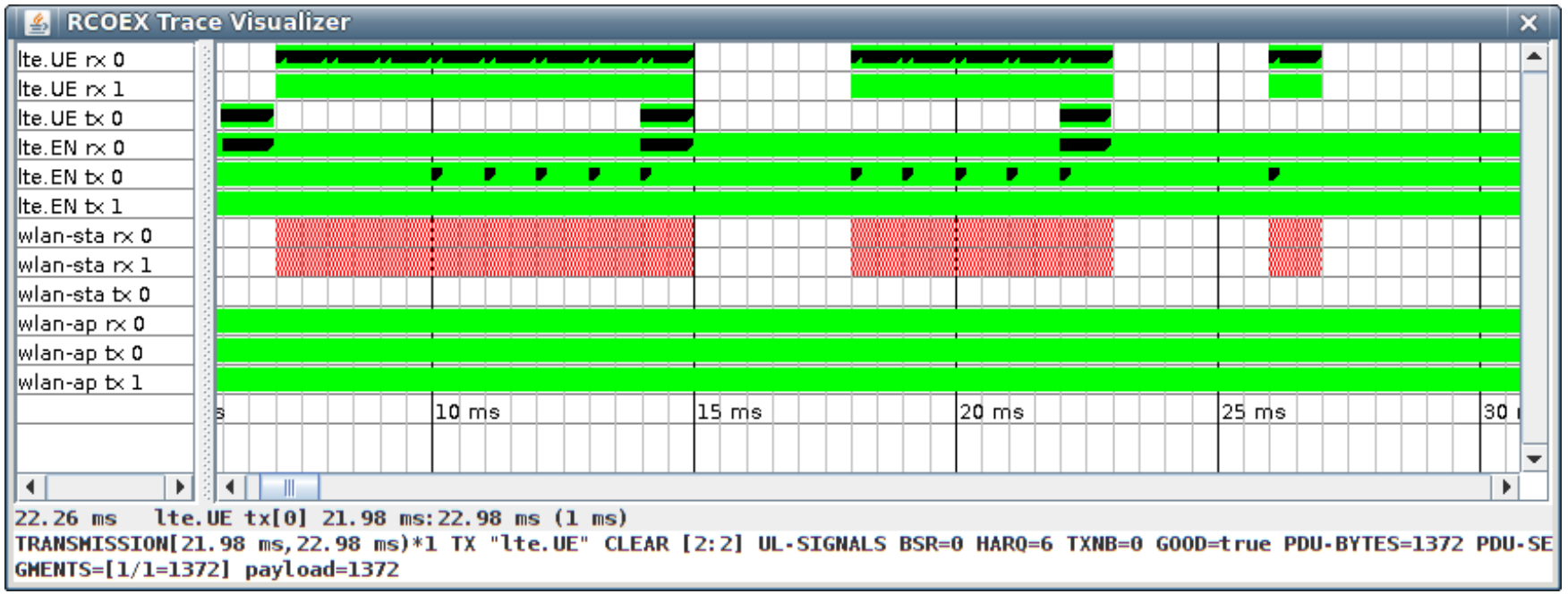
Simulating LTE (4)

- Ackn and next grant



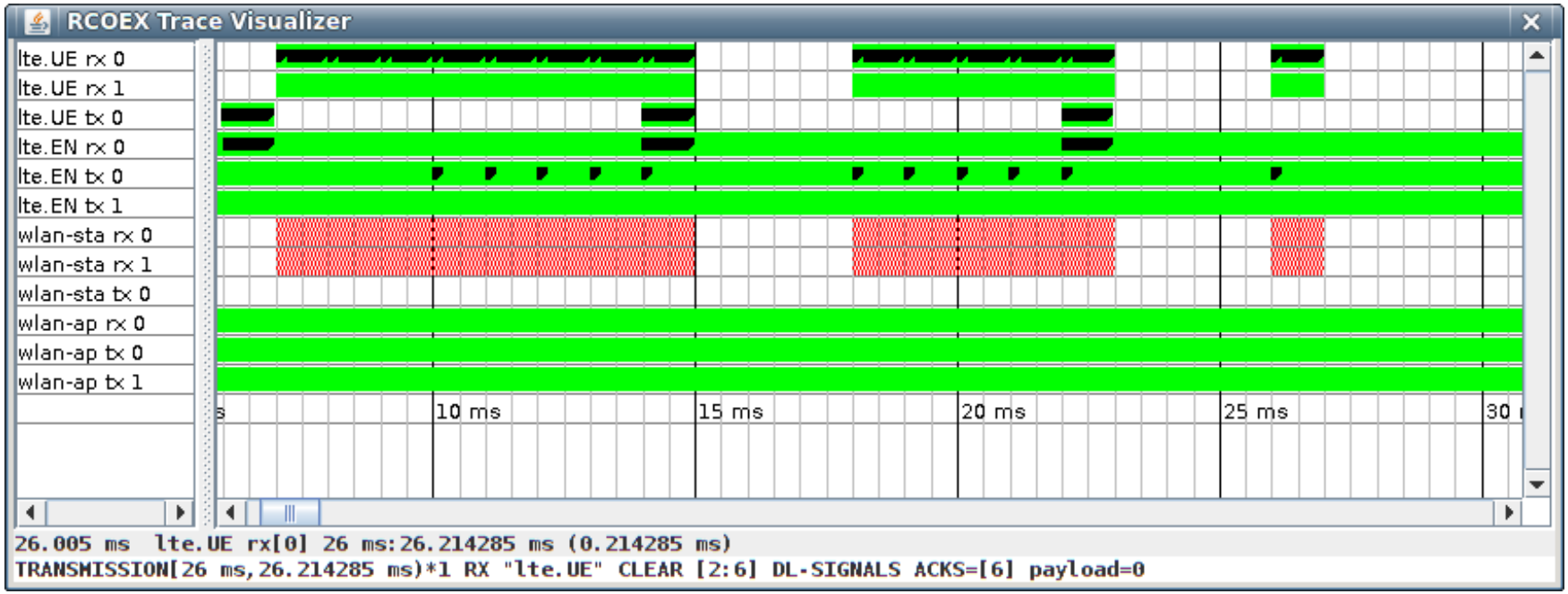
Simulating LTE (5)

- Rest of data



Simulating LTE (6)

- Final ackn



WiFi development

	year	Speed	PHY	frequency	Bandw.
802.11-1997	1997	2Mbps	FH-DSSS	900/2.4MHz	20MHz
802.11b	1999	11Mbps	DSSS	2.4MHz	20MHz
802.11a	1999	54Mbps	OFDM	5MHz	20MHz
802.11g	2003	54Mbps	OFDM	2.4HHz	20MHz
802.11n	2009	150-600	OFDM	2.4/5MHz	20-40
802.11-2012	2012	150-600	OFDM	2.4/5MHz	20-40
802.11ac	2014	300-6700	OFDM	2.4/5MHz	80-160
802.11ad	2014	~7000	OFDM?	2.4/5/60MHz	

LTE development

- Release 8
  - Initial LTE
- Release 9
  - Networks and services (emergency/location/multicasting/femtocells) but minimal changes to PHY/MAC
- Release 10
  - (LTE-A, complete): Improved PHY/MAC: carrier aggregation, SU-MIMO
- Release 11
  - (LTE-A, any time now...): Services, new carrier aggregation combinations, Cooperative multipoint, initial in-device coexistence
- Release 12
  - (LTE-A evolved, in development): new carrier type (NCT), 3D MIMO, LTE/WiFi integration. . .