

Long Term Evolution (LTE) - A Tutorial

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Outline

- 1 Introduction
- 2 LTE Architecture
- 3 LTE Radio Interface
- 4 Multimedia Broadcast/Multicast Service
- 5 LTE Deployment Considerations
- 6 Work Related to Video Streaming
- 7 Conclusions

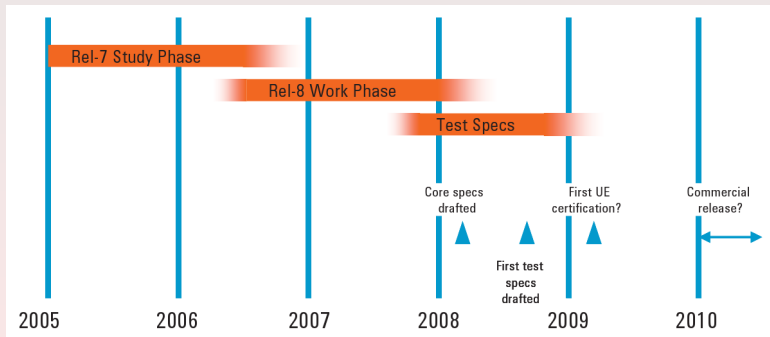
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Introduction

- In November 2004 3GPP began a project to define the long-term evolution of UMTS cellular technology.
- Related specifications are formally known as the evolved UMTS terrestrial radio access (E-UTRA) and evolved UMTS terrestrial radio access network (E-UTRAN).
- First version is documented in Release 8 of the 3GPP specifications.
- Commercial deployment not expected before 2010, but there are currently many field trials.

LTE Development Timeline



Next Generation Mobile Network (NGMN) Alliance



19 worldwide leading mobile operators

LTE Targets

- Higher performance
 - 100 Mbit/s peak downlink, 50 Mbit/s peak uplink
 - 1G for LTE Advanced
 - Faster cell edge performance
 - Reduced latency (to 10 ms) for better user experience
 - Scalable bandwidth up to 20 MHz
- Backwards compatible
 - Works with GSM/EDGE/UMTS systems
 - Utilizes existing 2G and 3G spectrum and new spectrum
 - Supports hand-over and roaming to existing mobile networks
- Reduced capex/opex via simple architecture
 - reuse of existing sites and multi-vendor sourcing
- Wide application
 - TDD (unpaired) and FDD (paired) spectrum modes
 - Mobility up to 350kph
 - Large range of terminals (phones and PCs to cameras)

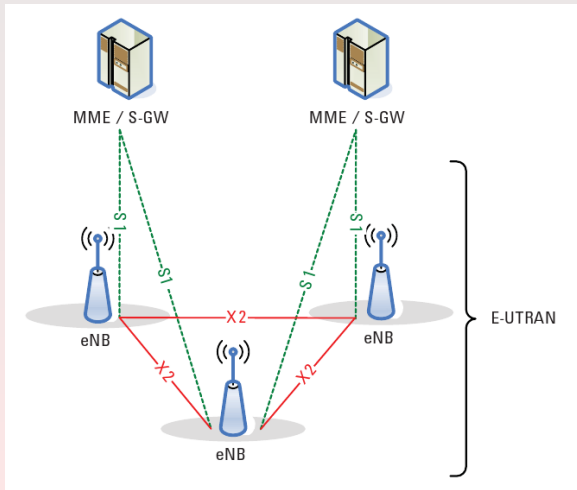
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LTE Architecture

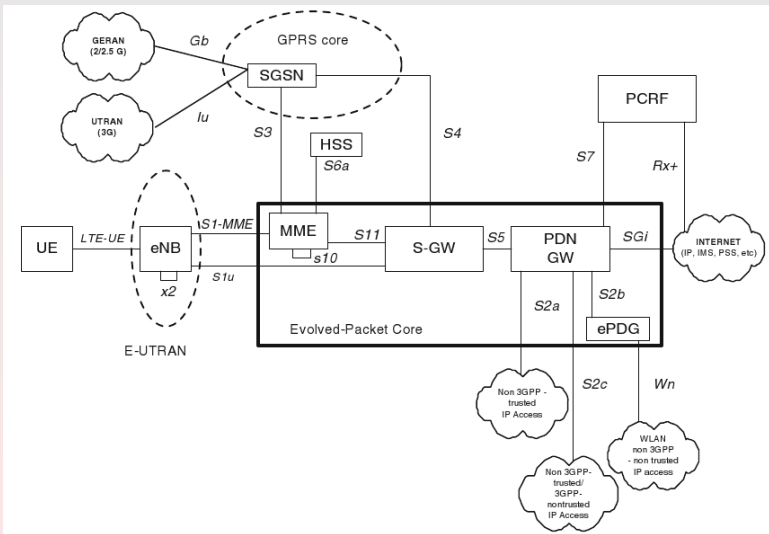
- LTE encompasses the evolution of:
 - the radio access through the E-UTRAN
 - the non-radio aspects under the term **System Architecture Evolution (SAE)**
- Entire system composed of both LTE and SAE is called the **Evolved Packet System (EPS)**
- At a high-level, the network is comprised of:
 - Core Network (CN), called **Evolved Packet Core (EPC)** in SAE
 - access network (E-UTRAN)
- A *bearer* is an IP packet flow with a defined QoS between the gateway and the User Terminal (UE)
- CN is responsible for overall control of UE and establishment of the bearers

LTE Architecture



LTE Architecture

- Main logical nodes in EPC are:
 - PDN Gateway (**P-GW**)
 - Serving Gateway (**S-GW**)
 - Mobility Management Entity (**MME**)
- EPC also includes other nodes and functions, such:
 - Home Subscriber Server (HSS)
 - Policy Control and Charging Rules Function (PCRF)
- EPS only provides a bearer path of a certain QoS, control of multimedia applications is provided by the IP Multimedia Subsystem (IMS), which considered outside of EPS
- E-UTRAN solely contains the evolved base stations, called **eNodeB** or **eNB**

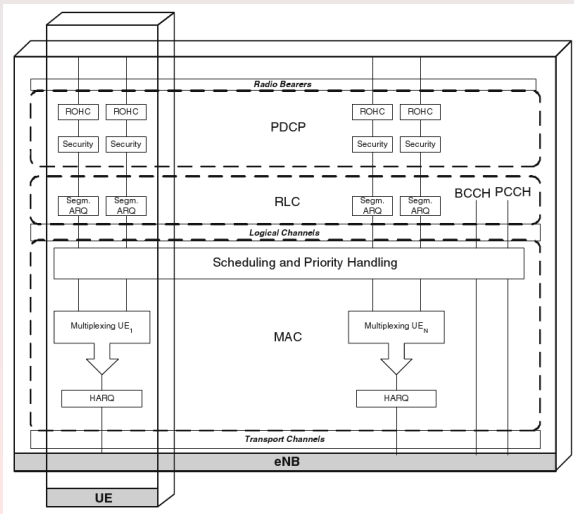


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LTE Radio Interface Architecture

- eNB and UE have *control plane* and *data plane* protocol layers



Data enters processing chain in the form of IP packets on one of the SAE bearers

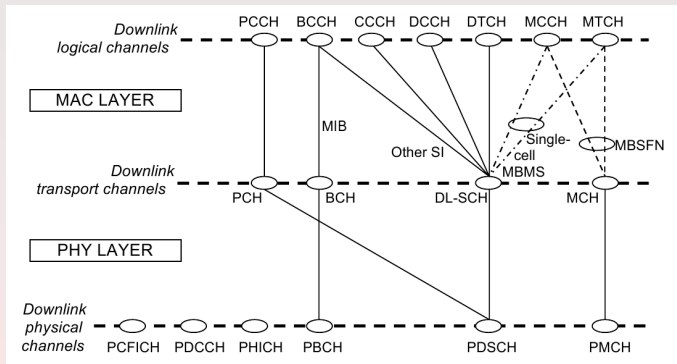
Protocol Layers

- IP packets are passed through multiple protocol entities:
 - **Packet Data Convergence Protocol (PDCP)**
 - IP header compression based on Robust Header Compression (ROHC)
 - ciphering and integrity protection of transmitted data
 - **Radio Link Control (RLC)**
 - segmentation/concatenation
 - retransmission handling
 - in-sequence delivery to higher layers
 - **Medium Access Control (MAC)**
 - handles hybrid-ARQ retransmissions
 - uplink and downlink scheduling at the eNodeB
 - **Physical Layer (PHY)**
 - coding/decoding
 - modulation/demodulation (OFDM)
 - multi-antenna mapping
 - other typical physical layer functions

Communication Channels

- RLC offers services to PDCP in the form of *radio bearers*
- MAC offers services to RLC in the form of *logical channels*
- PHY offers services to MAC in the form of *transport channels*
- A *logical channel* is defined by the type of information it carries. Generally classified as:
 - a control channel, used for transmission of control and configuration information necessary for operating an LTE system
 - a traffic channel, used for the user data
- A *transport channel* is defined by how and with what characteristics the information is transmitted over the radio interface

Channel Mapping



- BCCH: Broadcast
- CCCH: Common
- PCCH: Paging
- MCCH: Multicast
- DTCH: Dedicated Traffic
- MTCH: Multicast Traffic
- DL-SCH: Downlink Shared
- MCH: Multicast
- BCH: Broadcast
- PCH: Paging

Radio Link Control (RLC) Layer

- Depending on the scheduler decision, a certain amount of data is selected for transmission from the RLC SDU buffer and the SDUs are segmented/concatenated to create the RLC PDU. Thus, for LTE the RLC PDU size varies dynamically
- Each RLC PDU includes a header, containing, among other things, a sequence number used for in-sequence delivery and by the retransmission mechanism
- A retransmission protocol operates between the RLC entities in the receiver and transmitter.
 - Receiver monitors sequence numbers and identifies missing PDUs
- Although the RLC is capable of handling transmission errors, error-free delivery is in most cases handled by the MAC-based hybrid-ARQ protocol

Medium Access Control (MAC) Layer

- Data on a transport channel is organized into transport blocks.
- Each Transmission Time Interval (TTI), at most one transport block of a certain size is transmitted over the radio interface to/from a mobile terminal (in absence of spatial multiplexing)
- Each transport block has an associated Transport Format (TF)
 - specifies how the block is to be transmitted over the radio interface (e.g. transport-block size, modulation scheme, and antenna mapping)
- By varying the transport format, the MAC layer can realize different data rates.
 - Rate control is therefore also known as transport-format selection

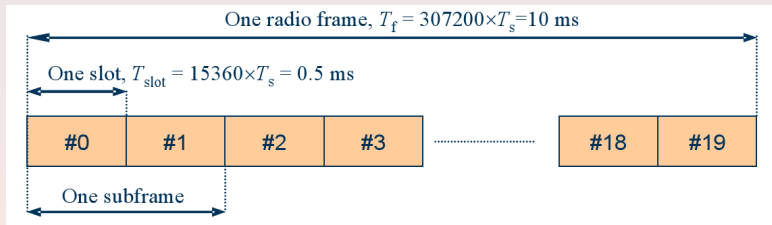
Hybrid ARQ (HARQ)

- In hybrid ARQ, multiple parallel stop-and-wait processes are used (this can result in data being delivered from the hybrid-ARQ mechanism out-of-sequence, in-sequence delivery is ensured by the RLC layer)
- Hybrid ARQ is not applicable for all types of traffic (broadcast transmissions typically do not rely on hybrid ARQ). Hence, hybrid ARQ is only supported for the DL-SCH and the UL-SCH

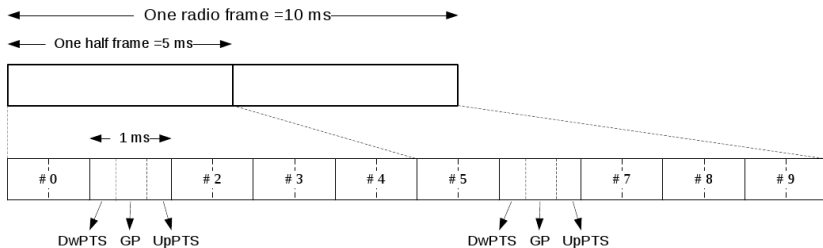
Physical (PHY) Layer

- Based on OFDMA with cyclic prefix in downlink, and on SC-FDMA with a cyclic prefix in the uplink
- Three duplexing modes are supported: full duplex FDD, half duplex FDD, and TDD
- Two frame structure types:
 - Type-1 shared by both full- and half-duplex FDD
 - Type-2 applicable to TDD
- A radio frame has a length of 10 ms and contains 20 slots (slot duration is 0.5 ms)
- Two adjacent slots constitute a *subframe* of length 1 ms
- Supported modulation schemes are: QPSK, 16QAM, 64QAM
- Broadcast channel only uses QPSK
- Maximum information block size = 6144 bits
- CRC-24 used for error detection

Type-1 Frame



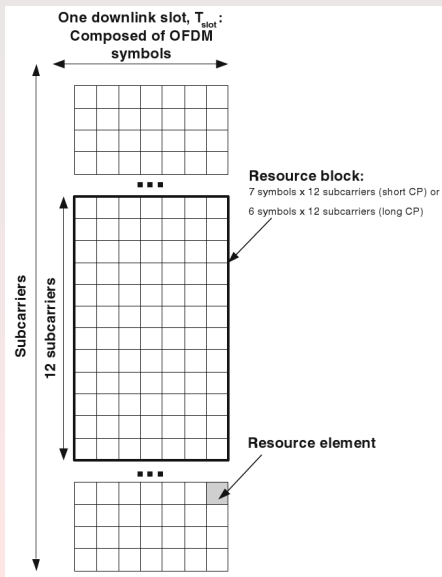
Type-2 Frame

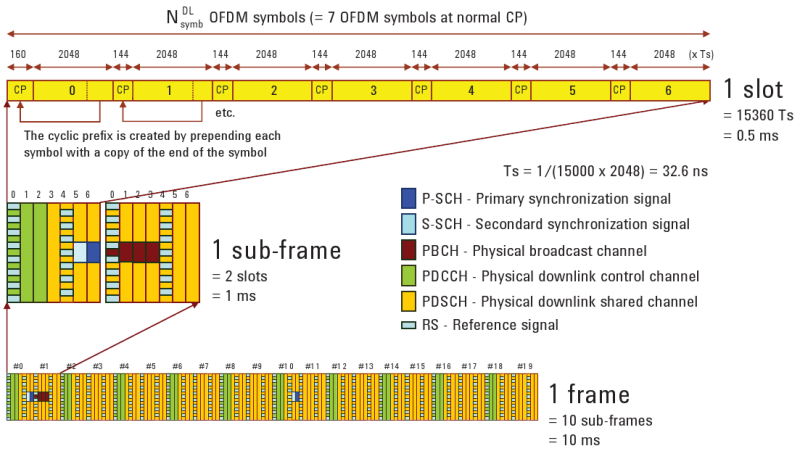


Configuration	Switch-point periodicity	Subframe number									
		0	1	2	3	4	5	6	7	8	9
0	5 ms	D	S	U	U	U	D	S	U	U	U
1	5 ms	D	S	U	U	D	D	S	U	U	D
2	5 ms	D	S	U	D	D	D	S	U	D	D
3	10 ms	D	S	U	U	U	D	D	D	D	D
4	10 ms	D	S	U	U	D	D	D	D	D	D
5	10 ms	D	S	U	D	D	D	D	D	D	D
6	10 ms	D	S	U	U	U	D	S	U	U	D

- Scheduler in eNB (base station) allocates resource blocks (which are the smallest elements of resource allocation) to users for predetermined amount of time
- Slots consist of either 6 (for long cyclic prefix) or 7 (for short cyclic prefix) OFDM symbols
- Longer cyclic prefixes are desired to address longer fading
- Number of available subcarriers changes depending on transmission bandwidth (but subcarrier spacing is fixed)

Downlink Resource Block





- To enable channel estimation in OFDM transmission, known reference symbols are inserted into the OFDM time-frequency grid.
- In LTE, these reference symbols are jointly referred to as downlink reference signals.
- Three types of reference signals are defined for the LTE downlink:
 - Cell-specific downlink reference signals
 - transmitted in every downlink subframe, and span the entire downlink cell bandwidth.
 - UE-specific reference signal
 - only transmitted within the resource blocks assigned for DL-SCH transmission to that specific terminal
 - MBSFN reference signals

MAC Scheduler

- eNB scheduler controls the time/frequency resources for a given time for uplink and downlink
 - dynamically controls the terminal(s) to transmit to and, for each of these terminals, the set of resource blocks upon which the terminal's DL-SCH should be transmitted
- Scheduler dynamically allocates resources to UEs at each TTI
- The scheduling strategy is implementation specific and not specified by 3GPP
 - scheduler selects best multiplexing for UE based on channel conditions
 - preferably schedule transmissions to a UE on resources with advantageous channel condition

- Most scheduling strategies need information about:
 - channel conditions at the terminal
 - buffer status and priorities of the different data flows
 - interference situation in neighboring cells (if some form of interference coordination is implemented)
- UE transmits
 - channel-status reports reflecting the instantaneous channel quality in the time and frequency domains
 - information necessary to determine the appropriate antenna processing in case of spatial multiplexing
- Downlink LTE considers the following schemes as a scheduler algorithm:
 - Frequency Selective Scheduling (FSS)
 - Frequency Diverse Scheduling (FDS)
 - Proportional Fair Scheduling (PFS)
- Interference coordination, which tries to control the inter-cell interference on a slow basis, is also part of the scheduler

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Multimedia Broadcast/Multicast Service (MBMS)

- Introduced for WCDMA (UMTS) in Release 6
- Supports multicast/broadcast services in a cellular system
- Same content is transmitted to multiple users located in a specific area (MBMS service area) in a unidirectional fashion
- MBMS extends existing 3GPP architecture by introducing:
 - *MBMS Bearer Service*
 - delivers IP multicast datagrams to multiple receivers using minimum radio and network resources and provides an efficient and scalable means to distribute multimedia content to mobile phones
 - *MBMS User Services*
 - streaming services - a continuous data flow of audio and/or video is delivered to the user's handset
 - download services - data for the file is delivered in a scheduled transmission timeslot

Multimedia Broadcast/Multicast Service (MBMS)

- QoS for transport of multimedia applications is not sufficiently high to support a significant portion of the users for either download or streaming applications
 - The p-t-m MBMS Bearer Service does neither allow control, mode adaptation, nor retransmitting lost radio packets
- Consequently, 3GPP included an application layer FEC based on Raptor codes for MBMS
- MBMS User Services may be distributed over p-t-p links (if more efficient)
- **Broadcast Multicast Service Center (BM-SC)** node
 - responsible for authorization and authentication of content provider, charging, and overall data flow through Core Network (CN)
- In case of multicast, a request to join the session has to be sent to become member of the corresponding MBMS service group

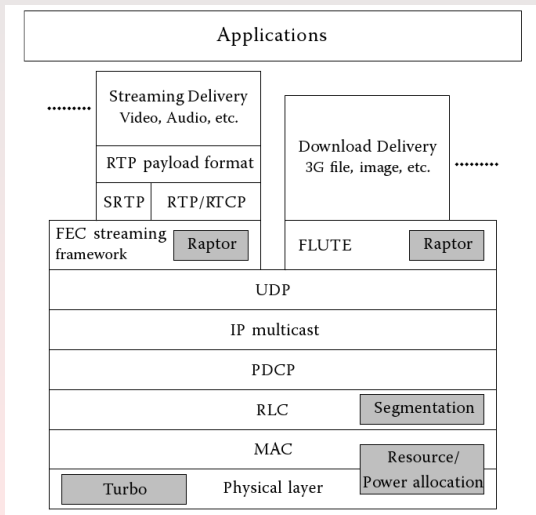
Multimedia Broadcast/Multicast Service (MBMS)

- MBMS data streams are not split until necessary
- MBMS services are power limited and maximize the diversity without relying on feedback from users
- Two techniques are used to provide diversity:
 - Macro-diversity: combining transmission from multiple cells
 - Soft combining: combines the soft bits received from the different radio links prior to (Turbo) coding
 - Selection combining: decoding the signal received from each cell individually, and for each TTI selects one (if any) of the correctly decoded data blocks for further processing by higher layers
 - Time-diversity:
 - using a long TTI and application-level coding to combat fast fading

Multimedia Broadcast/Multicast Service (MBMS)

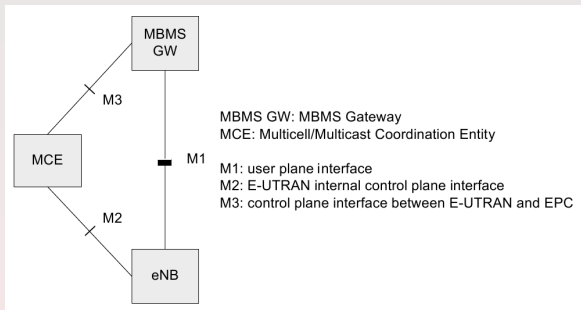
- Streaming data are encapsulated in RTP and transported using the FLUTE protocol when delivering over MBMS bearers
- MAC layer maps and multiplexes the RLC-PDUs to the transport channel and selects the transport format depending on the instantaneous source rate
- MBMS uses the Multimedia Traffic Channel (MTCH), which enables p-t-m distribution. This channel is mapped to the Forward Access Channel (FACH), which is finally mapped to the Secondary-Common Control Physical Channel (S-CCPCH)
- The TTI is transport channel specific and can be selected from the set 10 ms, 20 ms, 40 ms, 80 ms for MBMS

Multimedia Broadcast/Multicast Service (MBMS)



LTE Evolved MBMS (eMBMS)

- Will be defined in Release 9 of the 3GPP specifications
 - currently in progress, expected to be frozen in Dec 2009
- Multimedia service can be provided by either: *single-cell broadcast* or *multicell mode* (aka **MBMS Single Frequency Network (MBSFN)**)
- In an MBSFN area, all eNBs are synchronized to perform simulcast transmission from multiple cells (each cell transmitting identical waveform)
- If user is close to a base station, delay of arrival between two cells could be quite large, so the subcarrier spacing is reduced to 7.5 KHz and longer CP is used
- Main advantages over technologies such as DVB-H or DMB:
 - no additional infrastructure
 - operator uses resources that are already purchased
 - user interaction is possible



- MCE coordinates the synchronous multi-cell transmission
- The MCE can physically be part of the eNB → flat architecture

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LTE Deployment Considerations

- Voice and SMS (main source of revenue for telecom companies)
 - Circuit Switch Fallback (CS Fallback)
 - IMS-based VoIP
 - Voice over LTE via Generic Access (VoLGA)
- Roaming revenues from current GSM networks (gone)
- Interoperability with existing legacy technologies (including GSM, WCDMA, CDMA2000, WiMAX and others)
- Leverage existing 3G capacity and coverage (make use of existing equipment)
- Service provision (not being a dumb bit pipe provider)
- Security (especially EPC)
- terminal devices (balancing battery life with MIMO support, and how much legacy support)

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Mobile Video Transmission Using Scalable Video Coding

- Investigating per packet QoS would enable general packet marking strategies (such as Differentiated Services). This can be done by either:
 - Mapping SVC priority information to Differentiated Services Code Point (DSCP) to introduce per packet QoS
 - Making the scheduler media-aware (e.g. by including some MANE-like functionality), and therefore able to use priority information in the SVC NAL unit header
- Many live-media distribution protocols are based on RTP, including p-t-m transmission (e.g. DVB-H or MBMS). Provision of different layers, on different multicast addresses for example, allows for applying protection strength on different layers
- By providing signalling in the RTP payload header as well as in the SDP session signalling, adaptation (for bitrate or device capability) can be applied in the network by nodes typically known as **MASEU**

Downlink OFDM Scheduling and Resource Allocation for Delay Constrained SVC Streaming

- Problem Definition:
 - Designing efficient multi-user video streaming protocols that fully exploit the resource allocation flexibility in OFDM and performance scalabilities in SVC
- Maximize average PSNR for all video users under a total downlink transmission power constraint based on a stochastic subgradient-based scheduling framework
- Authors generalize their previous downlink OFDM resource allocation algorithm for elastic data traffic to real-time video streaming by further considering dynamically adjusted priority weights based on the current video content, deadline requirements, and the previous transmission results

Scalable and Media Aware Adaptive Video Streaming over Wireless Networks

- A packet scheduling algorithm (in MANE) which operates on the different substreams of the main scalable video stream
- Exploit SVC coding to provide a subset of hierarchically organized substreams at the RLC layer entry point and utilize the scheduling algorithm to select scalable substreams to be transmitted to RCL layer depending on the channel transmission conditions
- General idea:
 - perform fair scheduling between scalable substreams until deadline of oldest unsent data units with higher priorities is approaching
 - do not maintain fairness if deadline is expected to be violated, packets with lower priorities are delayed in a first time and later dropped if necessary
- In addition, SVC coding is tuned, leading to a generalized scalability scheme including regions of interest (ROI) (combining ROI coding with SNR and temporal scalability)

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Conclusions

- LTE and SAE will be the unified 4G wireless network
 - Backwards compatible
 - Multiple upgrade paths
 - Significant carrier commitment
- eMBMS seems promising for delivering multimedia content over LTE (at least in theory) and without the need for a separate infrastructure
- LTE still faces some deployment challenges (but are currently being studied)
- Research interest in optimized streaming video via eMBMS

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Thank You

Questions?