An Adaptive MAC Layer Protocol for ATM-based LEO Satellite Networks

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An Access Protocol for Mobile Satellite Users with Reduced Link Margins and Contention Probability

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Introduction
Project Framework & System Architecture

ATM-Sat Project

- Design of system architecture
- Development of proof-of-concept demonstrator
- Support of mobile, fixed, and portable terminals
- Guaranteed QoS
- Switching and Routing in the sky (ATM switch as payload)

Satellite Constellation
(M-Star Constellation)

- LEO orbit (1350 km)
- Walker 72 satellites, 12 planes, 47° inclined
- 20° min. elevation angle
- Optical ISLs

Link Parameters

- Ka-Band
- approx. 2 Mbit/s in the uplink
- approx. 32 Mbit/s in the downlink

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Protocol Design

Considerations	(1)	Single ATM-cell lacks of a dedicated QoS field
	(2)	Variable Propagation Delay
	(3)	- Change in elevation angle --> changing error rates
		- Severe impact of rain attenuation
		- Shadowing (moving terminals)
Solutions	(1)	- Layer Management Entity / Extension of protocol stack
		- Adaptive MAC framing structure
	(2)	- Appropriate guard times
	(3)	- Adaptive FEC Schemes
		- Shadowing too severe to be compensated by FEC

Protocol Design & Error Control
Protocol Stack and Adaptations

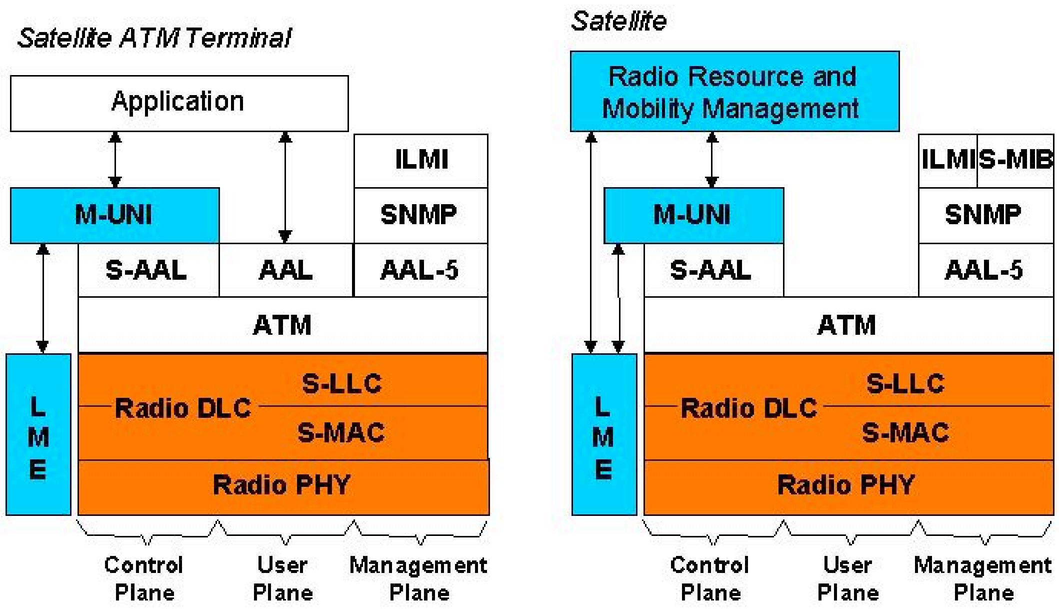
Terrestrial ATM:

Service parameter announced during connection set-up along with VPI/VCI (unique physical interface)

Satellite uses shared medium (radio link)

MAC Layer implements “Look-Up Table” to guarantee QoS constrains for different connections

Layer Management Entity connects UNI and MAC to bypass service parameters during connection establishment



Protocol Design & Error Control
Medium Access Control -- Overview

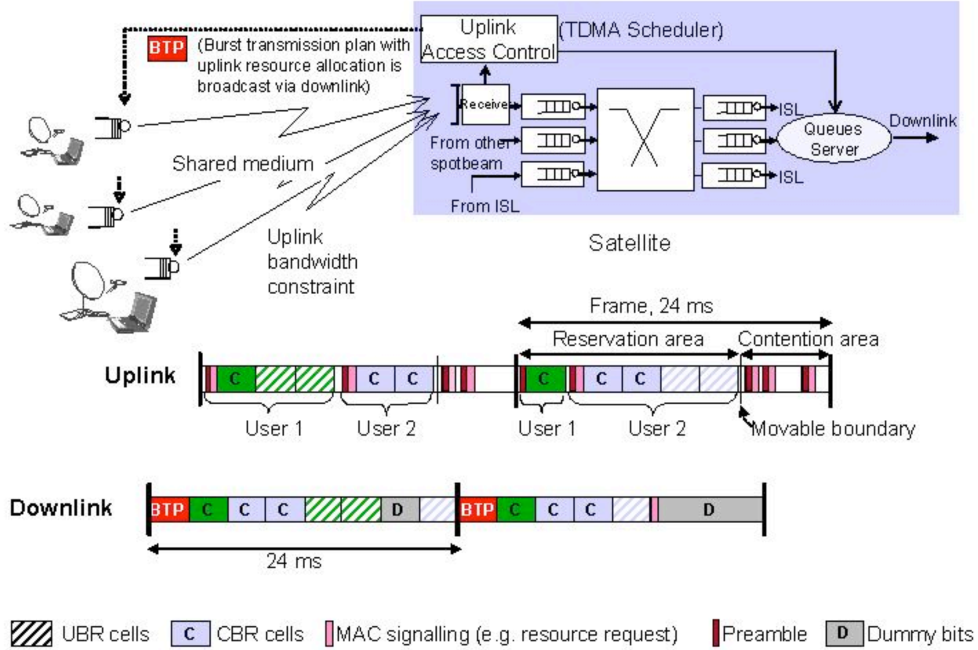
On-board XS control & scheduling

FDD in the up- & downlink

MF-TDMA scheme in the uplink

Multi-carrier demodulator serving several users --> Usage of extended VPI/VCIs based on terminal MAC ID

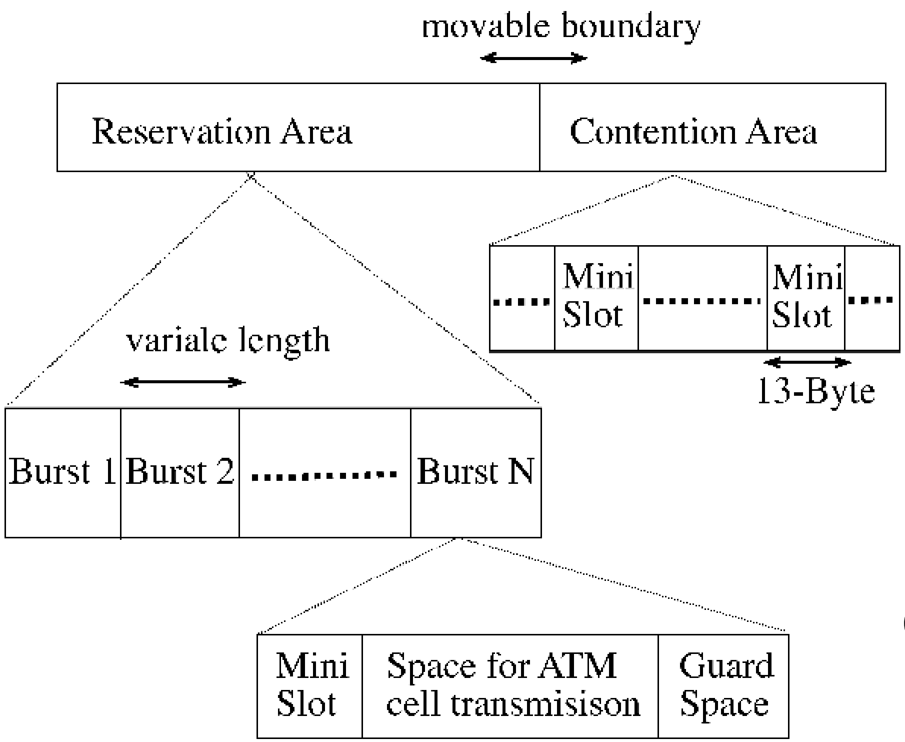
Frame length 24ms --> 16kbit/s bandwidth granularity with ATM cells



BTP contains resource assignment for next uplink frame

Reservation and Contention area with movable boundary --> reduces contention probability

Protocol Design & Error Control
Framing Structure Uplink-Frame



Reservation Area

Burst belongs to specific terminal, used to transmit pending ATM cells (and FEC bits)

Burst starts with Mini-Slot containing terminal MAC ID and signaling information to modify traffic profile

Variable length according to granted resources

Contention Area

Mini-Slot used for initial connection setup and resource allocation requests

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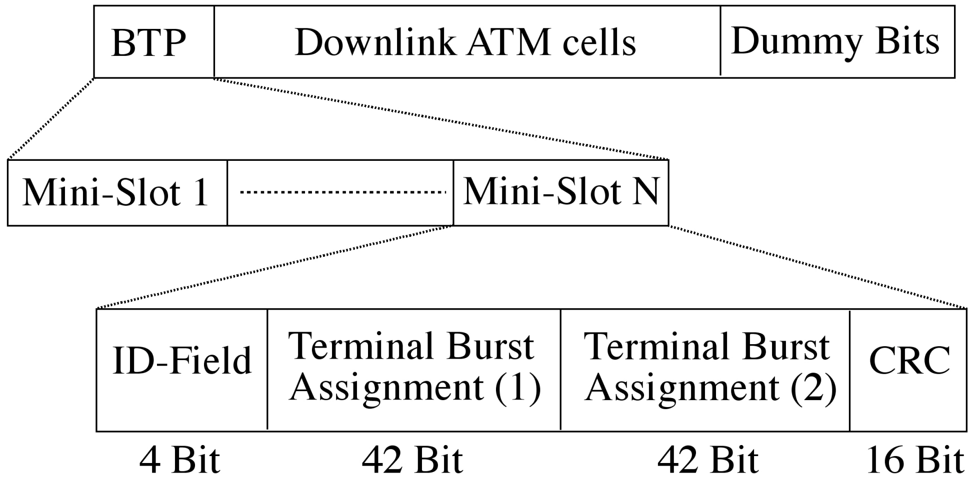
Protocol Design & Error Control
Framing Structure Downlink-Frame

Burst Transmission Plan:

- Assigns resource of the next uplink frame
- Consists of several Mini-Slots
- Each Mini-Slot contains resource assignments for up to two terminals
- Assignment tells terminal position and length of its uplink burst

Downlink ATM cells follow

Dummy bits added to guarantee 24-ms framing



Protocol Design & Error Control

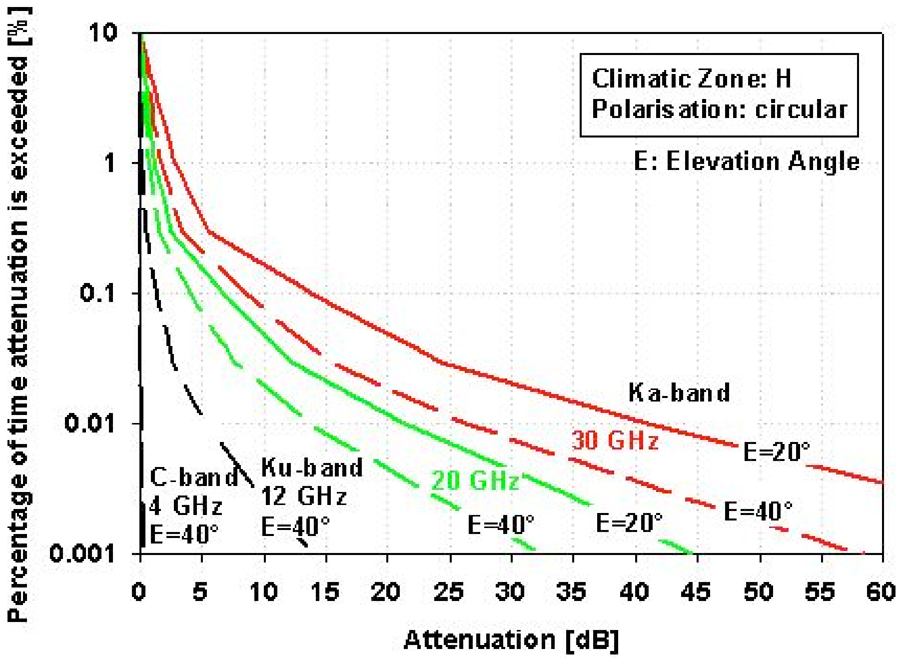
Overhead Associated with BTP

Definition	Overhead = max_length(BTP) / length(downlink frame)
Downlink Frame	Contains up to 2048 ATM cell + FEC ==> approx. 117 kByte
Burst Transmission Plan	Worst case: Every possible uplink ATM cell is assigned to a different terminal (= max number of terminal burst assignments) 125 ATM cells in the Uplink => 63 Mini-Slots needed ==> length(BTP) = 757 Byte

==> Overhead < 0.65%

Effective overhead is by far lower (burst contains more than one ATM cell)

Rain Attenuation & Link Availability



Attenuation in Ka-Band dominated by rain effects

Directional antennas eliminate multi-path fading

Rain attenuation appears only from time to time

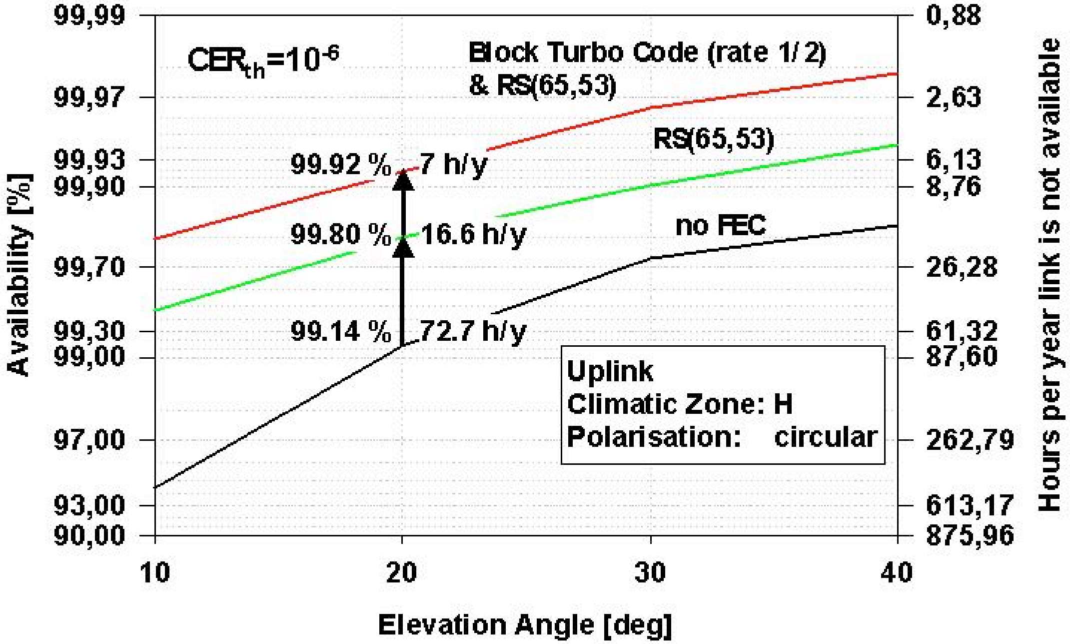
→ Adaptive FEC and modulation most efficiently use the available bandwidth

Goal: Cell Error Rate ≤ 10^{-6}

Protocol Design & Error Control
Link Availability with Adaptive Coding

Adaptive Coding:
- 4-byte CRC only
- RS(65,53)
- RS(65,53) & Rate 1/2 Turbo Code

Worst case: guarantee CER_{th} of 10^{-6} at min. elevation angle
- without FEC --> 99.14%
- RS(65/53) --> 99.80%
- convolutional code --> 99.92%



Protocol Design & Error Control

Efficiency of Adaptive FEC Schemes

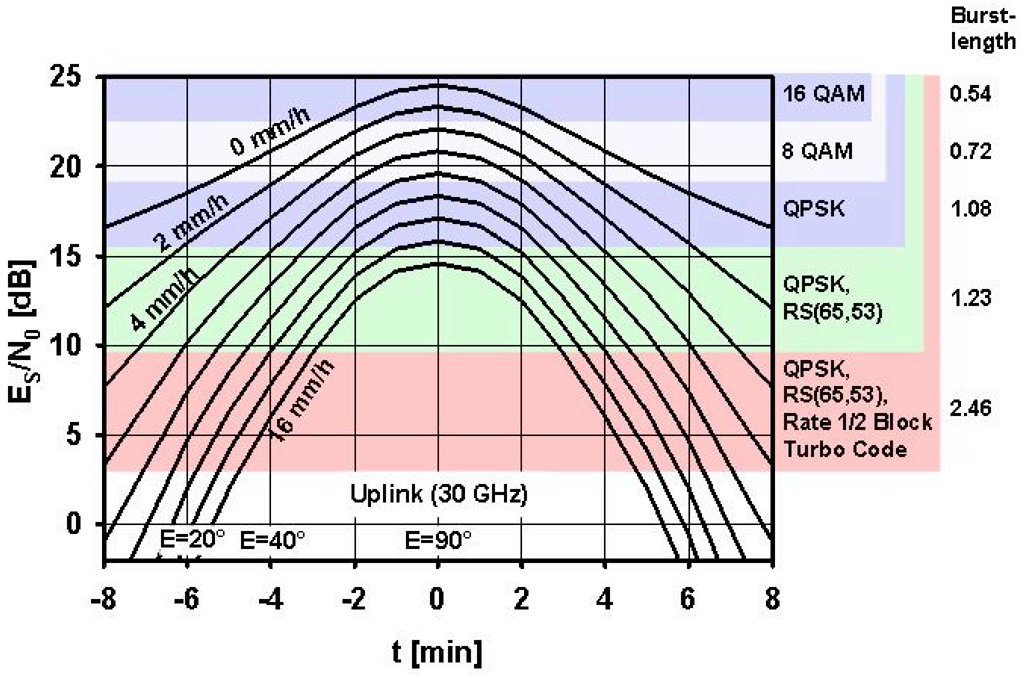
ABLP = Availability BurstLength Product

Constant RS(65/53) Coding	ABLP	=	99.8% * 65/53	
		=	1.22	
Adaptive Coding	ABLP	=	99.14% * 57/53	(4-byte CRC)
			+ 0.66% * 65/53	(RS-Code)
			+ 0.12% * 130/53	(RS & Turbo)
		=	1.08	

Adaptive Coding Scheme guarantees higher link availability for the given CER_{th} with an even better bandwidth utilization.

Protocol Design & Error Control

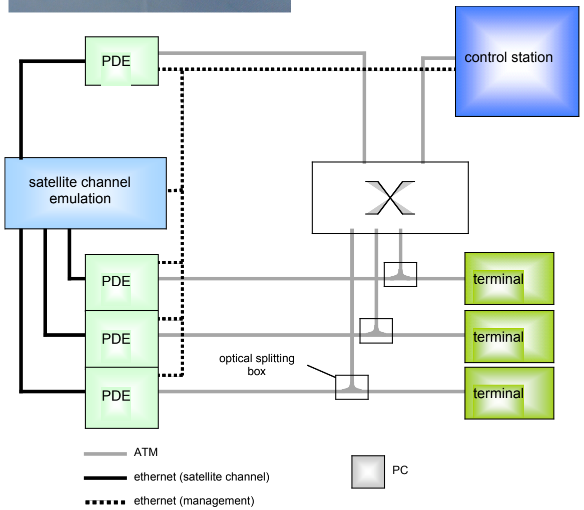
Adaptive FEC and Modulation Schemes



Rain attenuation occurs only occasionally

→Rainless periods with a rather good S/N_0 allow to switch modulation schemes

Protocol Implementation
Prototyping & Simulation Environment



Key Features:

Std. COTS components
Focus on target system
FreeBSD 5 current-version

Core Units:

Sat. channel emulator	Configurable via SNMP Adds variable delay Packet corruptions Shadowing
Protocol Dev. Entity	"External VSAT System" Netgraph used for devel.
Control Station	Initializes SCE & PDE

Measurements
Link Level Delay

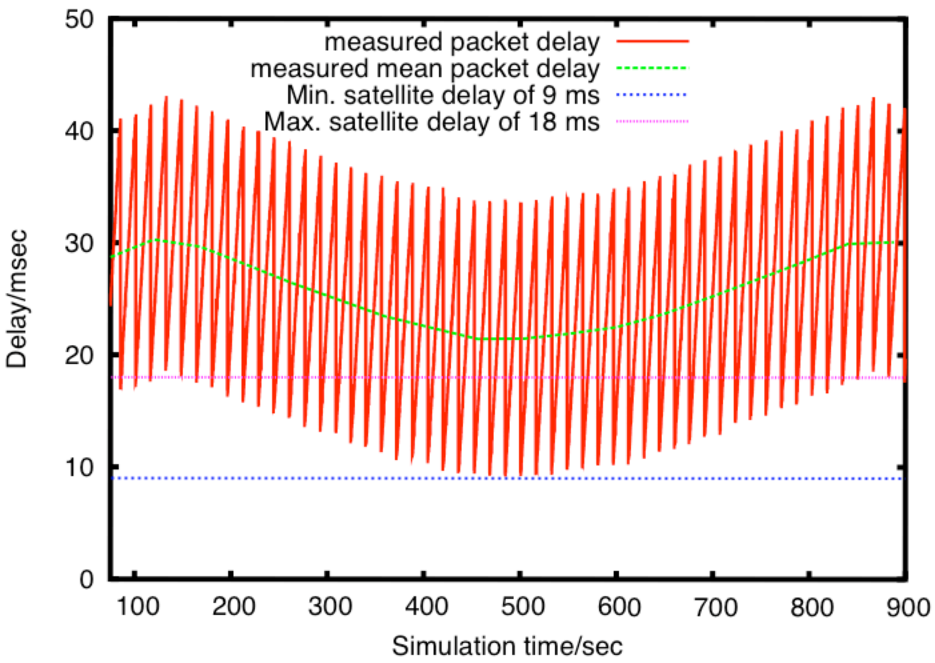
Sender cell rate: 1/24ms (one cell/frame)

Application and MAC not synchronized

Application computes time to send with regard to the start time of application, DLC starts a new 24-ms timer after every frame

→Jitter in clock may cause application to send cells at different times wrt. the beginning of a MAC Frame (cell may have to wait for next MAC frame)

→Measured mean delay 1/2 framelength larger than theory



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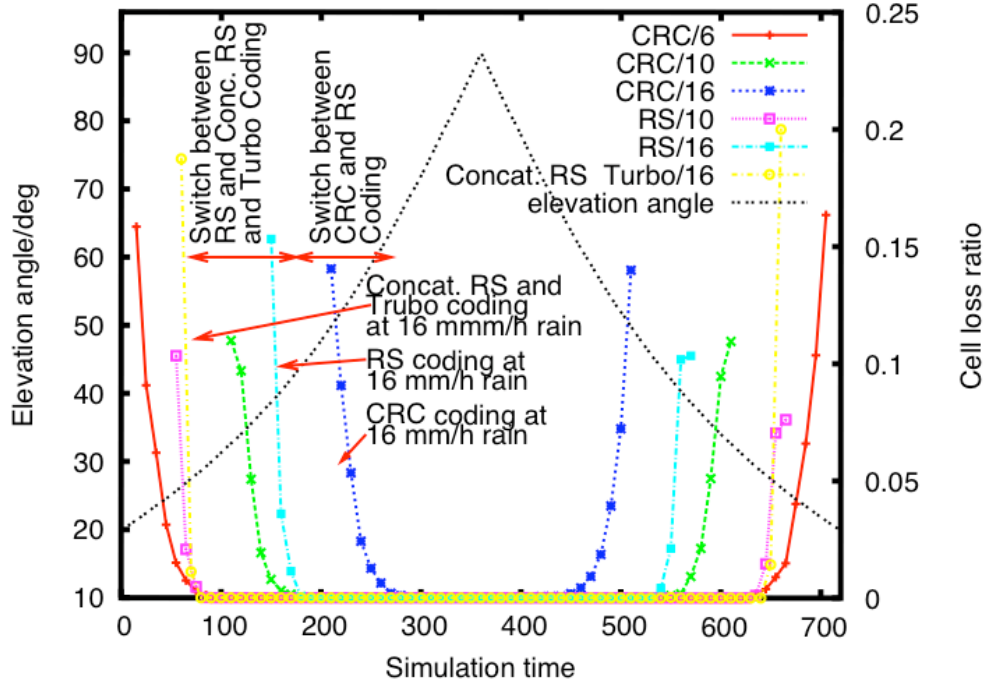
Measurements
Application Level Error Rates

Graph shows measured cell loss ratio for a given rain intensity (in mm/h) and coding scheme (CRC, RS, or Concatenated RS & Turbo)

Sophisticated coding schemes significantly improve availability at the cost of bandwidth

Simple CRC efficient for rainless periods and low rain intensities at high elevation angles.



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Conclusion

MAC protocol

- Adapts its coding and modulation scheme according to the experienced SNR and CER
- Increases the availability of the link for a given cell loss threshold
- Optimizes the bandwidth utilization
- Allows further optimization: E.g. “differential BTPs”

Measurements

- Proof of concept implementation used (available for FreeBSD)
- Illustrate advantages of adapting coding scheme according to rain intensity and elevation angle

Further Information

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