Application-layer FEC erasure codes and Cellular multicast/broadcast standards

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Digital Fountain

Mobile unicast delivery channel

- **(Almost) all delivery to mobile receivers uses unicast**
  - Each receiver consumes radio network resources
- **Based on continuous feedback from receiver of reception conditions, dynamically adjust**
  - Modulation parameters (BPSK → 16 QAM)
  - Error-correction scheme (rate 1/3 → 9/10)
  - ARQ of radio packets (with for example up to 3 retries)
  - Transmission power control
- **Typically, try to deliver a channel with less than 1% radio packet erasure rate**
  - Assume no upper level protection
  - Must be acceptable for all applications

The motivation for mobile broadcast/multicast

- **Multimedia content delivered is becoming richer**
  - Video clips – instant replay, news clips, advertising
  - Ring tones, stock information
  - Longer clips – sports events, concerts, interactive soap operas, short films, the entire news program, television
- **Operators are excited/worried about the future**
  - Exciting new revenue opportunities
  - Consume a lot more bandwidth to deliver – eating into current revenue-providing streams
  - Limited aggregate delivery capacity is available

The promise of mobile broadcast/multicast

- **Much multimedia content is popular**
  - Desired by many receivers
- **Use broadcast/multicast to delivery popular multimedia content**
  - Use same channel capacity independent of number of receivers
- **Operator interest**
  - No “blackouts” due to lack of capacity when there is very popular content
  - Off-load popular content to broadcast/multicast to preserve bulk of the capacity for high-revenue generating unicast applications
  - Scalable to bandwidth-hungry bulk delivery applications

Services offered by mobile broadcast/multicast

- **Electronic Service Guide**
  - Deliver a list of what is available when
- **File delivery**
  - Reliable file delivery
  - Delivery is typically scheduled and can happen with only minimal awareness from the end user
  - Playback to end user can be at a scheduled time or at the request of the end user after delivery
  - Foreground expedited delivery or background trickle delivery
- **Streaming**
  - Reliable streaming of A/V content
  - Reception and playback overlap
  - Generally scheduled playback time (reception can start before scheduled playback time)

Requirements of mobile broadcast/multicast

- **Electronic Service Guide delivery**
  - Generally a bunch of short files (but not always)
  - Needs to be reliably refreshed periodically
- **File delivery**
  - File sizes range from 10 KB up to several MB
  - Full reliable delivery typically required to “worst case” receiver
  - Efficient usage of radio resources is important
    - Most content delivered using the least amount of radio resources
  - Minimize receiver CPU requirements
    - Battery life
    - Other processes (like video, game) may be running during reception
  - Minimize receiver RAM requirements

Requirements of mobile broadcast/multicast

- **Streaming**
  - Streaming rates from 10 Kbps up to 256 Kbps+
  - Quality at least as good as unicast streaming required
    - This is the most popular streaming content offloaded from unicast
    - Will be a poor/unpopular service if end users perceive a drop-off in quality
  - Efficient usage of radio resources is important
    - Highest quality video for the least amount of radio resources
  - Minimize receiver CPU requirements
    - Battery life
    - Other processes (like video playout) will be running concurrently
  - Minimize receiver RAM requirements

Challenges of mobile broadcast/multicast

- **No feedback from receivers**
- **Same channel received by all receivers**
- **Receivers are in various locations with varying conditions**
- **None of the dynamic unicast channel protocols apply**
  - No adjustment of modulation parameters
  - No adjustment of error-correction scheme
  - No ARQ of radio packets
  - No transmission power control
  - Must set parameters pessimistically to guarantee at most 1% radio packet loss to “worst case” receiver
- **Even if 1% packet loss is achievable, if nothing else is provided**
  - Streaming quality will be poor
  - File delivery times will be very high – leading to high radio network consumption
- **Application-layer unicast reliability protocols not applicable**
  - No HTTP/FTP/TCP for file delivery
  - No HTTP/TCP for streaming
  - No RTP with retransmit for streaming

Needs of mobile broadcast/multicast

- **Standards**
  - Protocol for file delivery
  - Protocol for streaming
- **Technology**
  - Need to compensate for all the unicast reliability techniques that are not applicable
  - Provide efficient usage of radio resources
  - Provide high reliability/quality
- **Application-layer FEC standards and codes**
  - Fulfill the needs

Application-layer FEC standards and codes

Application-layer FEC codes

- **FEC codes that protect against IP packet loss**
  - Erasure codes – not error-correcting codes
- **Used in an application specific manner**
  - For file delivery – FEC encode the entire file
  - For streaming – FEC encode blocks of the stream
  - Exactly how the FEC encoder is used for an application
    - Must be tightly specified
    - Often reveal weakness/strengths of different FEC coding technology

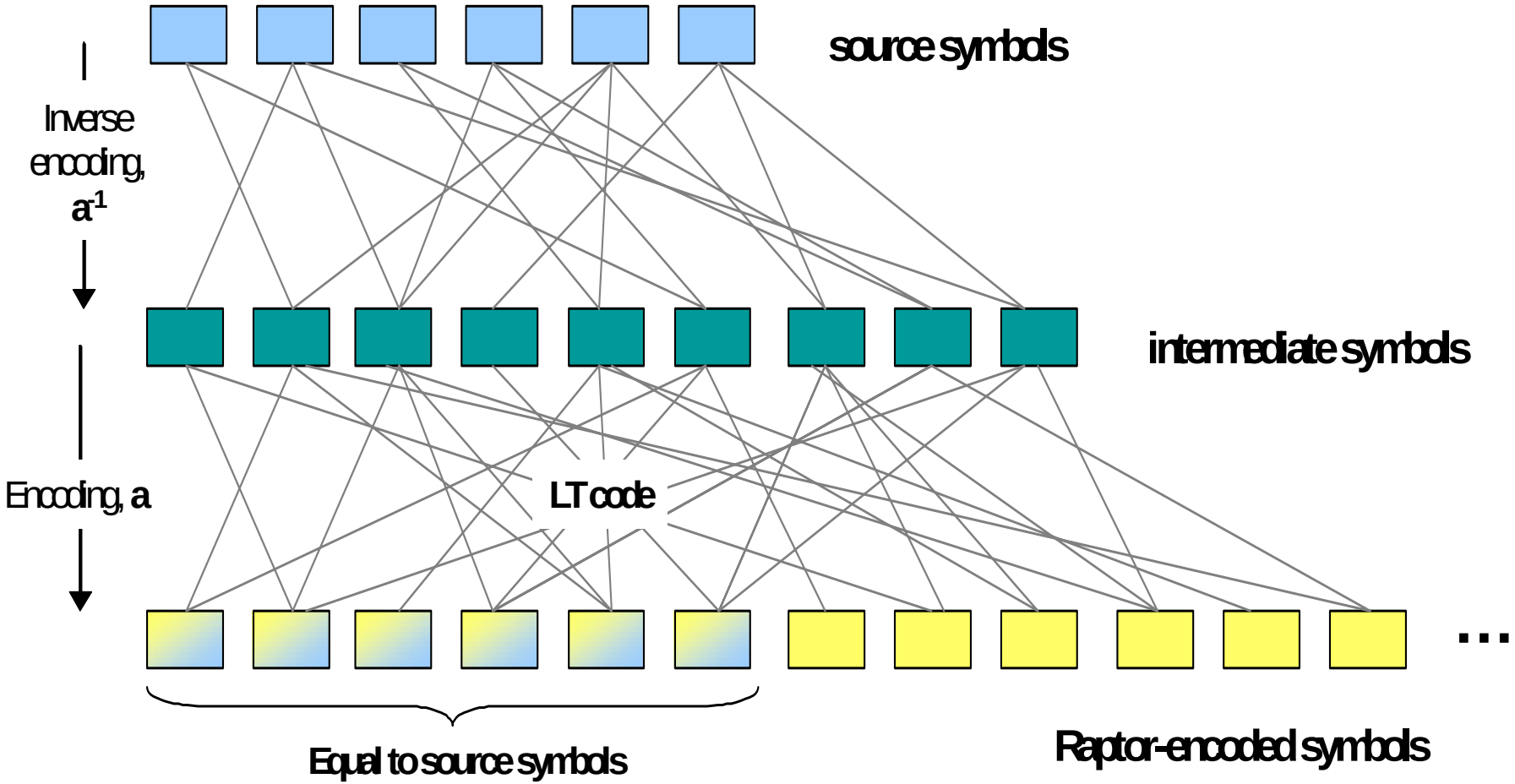
Application-layer FEC codes overview

- **Reed-Solomon history**
  - Invented in 1959
  - Well-known in coding theory community
  - Based on finite fields
- **Reed-Solomon technical**
  - Quadratic time encode/decode
  - Decoding time loss dependent
  - Very slow for high loss
  - Block code
    - 255 symbols at most
  - Systematic
  - Optimization in one dimension leads to poor trade-offs in other dimensions
- **Raptor history**
  - Invented in 2001
  - Well-known in coding theory community
  - Based on irregular LDPC
- **Raptor (R10) technical**
  - Linear time encode/decode
  - Decoding time loss independent
  - Order of magnitude faster
  - Fountain code
    - As many symbols as needed
  - Systematic
  - Optimized simultaneously in every practical dimension

Application-layer FEC codes in Mobile Standards

- **Reed-Solomon**
  - 3GPP MBMS
    - Evaluated extensively for both file delivery and streaming
    - Informal specification proposal
    - Not selected for either streaming or file delivery
  - DVB-H IPdatacast
    - Already exist at link layer
  - 3GPP2 BCMCS
    - Unknown
  - IETF
    - First draft of specification for file delivery
- **Raptor (R10)**
  - 3GPP MBMS
    - Evaluated extensively for both file delivery and streaming
    - Full formal specification
    - Selected for both streaming and file delivery
  - DVB-H IPdatacast
    - Evaluated extensively for file delivery
    - Full formal specification
    - Selected for file delivery
  - 3GPP2 BCMCS
    - Will be proposed for both streaming and file delivery
  - IETF
    - Full specification passed RMT wglc for file delivery

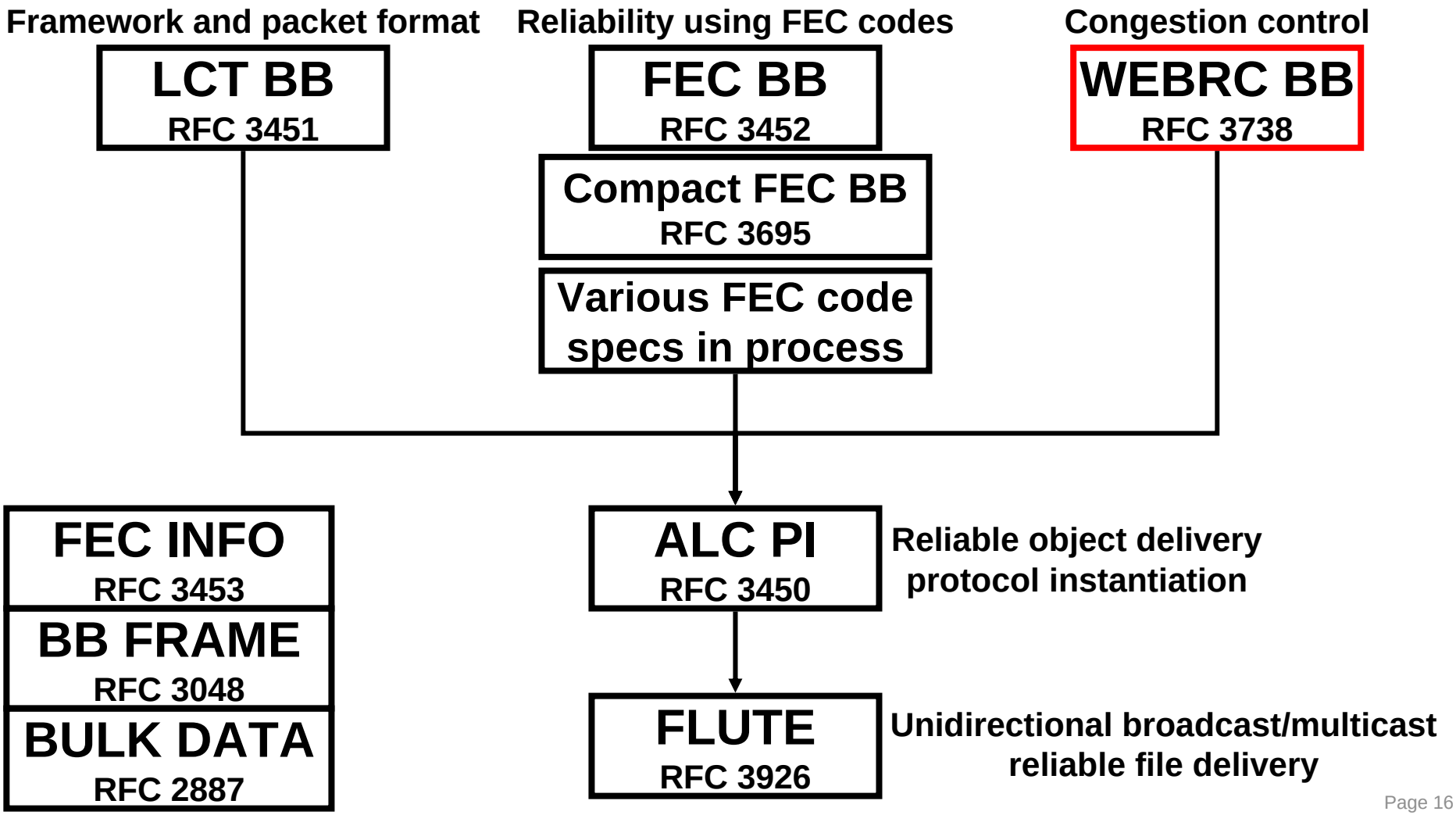
Raptor (R10)


source symbols
Inverse encoding, a^{-1}
intermediate symbols
Encoding, a
LT code
...
Equal to source symbols
Raptor-encoded symbols

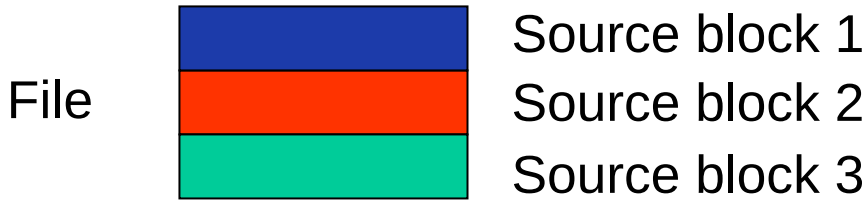
File delivery

- **FLUTE – Unidirectional file delivery protocol**
  - Developed within the IETF RMT working group
  - Provides session/file signaling mechanisms
  - Fundamentally uses application-layer FEC codes
    - Reliable delivery
    - Efficient delivery
  - Particular FEC code to be used not mandated
  - Various standardized FEC codes
  - Provides ability to use standardized FEC code of choice
  - Adoption by mobile broadcast/multicast standards
    - 3GPP MBMS
    - DVB-H IPdatacast
    - 3GPP2 BCMCS (at least ALC part of FLUTE)
    - …

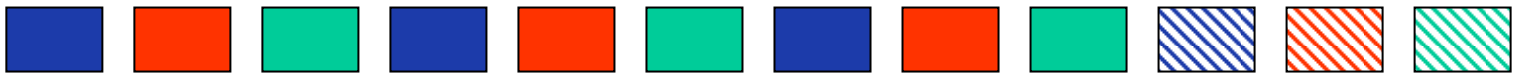
FLUTE


Framework and packet format
LCT BB
RFC 3451
Reliability using FEC codes
FEC BB
RFC 3452
Compact FEC BB
RFC 3695
Various FEC code specs in process
Congestion control
WEBRC BB
RFC 3738
FEC INFO
RFC 3453
BB FRAME
RFC 3048
BULK DATA
RFC 2887
ALC PI
RFC 3450
Reliable object delivery protocol instantiation
FLUTE
RFC 3926
Unidirectional broadcast/multicast reliable file delivery

FLUTE file delivery sender



Sent packets

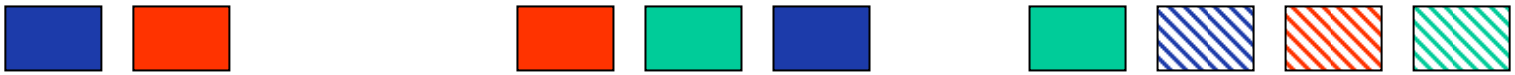


FEC encode each source block independently
to generate repair packets from source packets

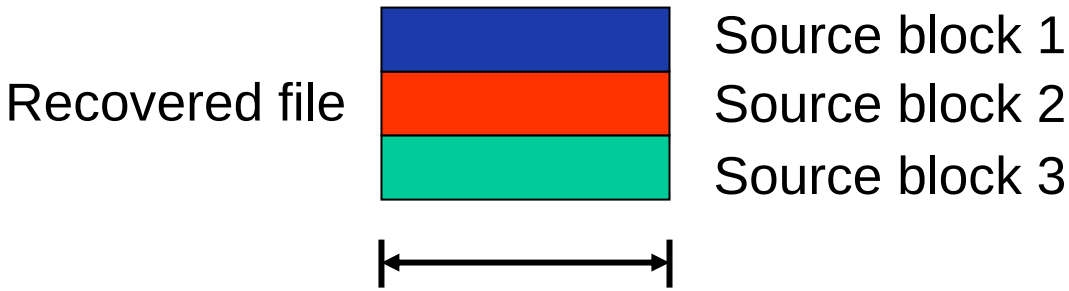
Send source packets first (intermixed)
Send repair packets after (intermixed)

FLUTE file delivery receiver

Received packets



FEC decode each source block independently
from received source and repair packets



Example of FEC scheme for FLUTE file delivery

- **FEC Encoding ID 1**
  - There must be an RFC that describes the FEC scheme
- **FEC Object Transmission Information**
  - FEC Encoding ID 1
  - Symbol size in bytes
  - Maximum source block size in symbols
  - File size in bytes
  - Algorithm automatically determines source block structure
- **FEC Payload ID (in FLUTE header)**
  - Source Block Number (2 bytes)
  - Encoding Symbol ID (2 bytes)

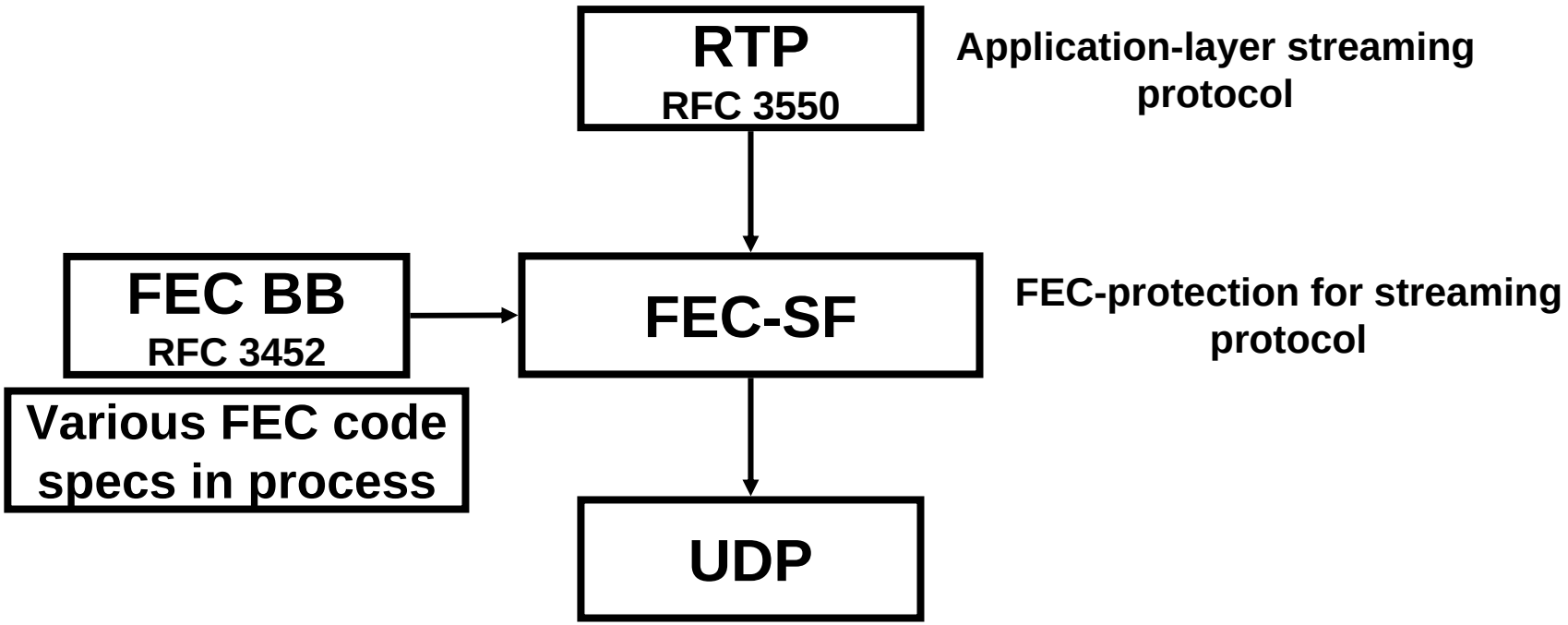
Streaming

- **RTP – Real-time transport protocol**
  - Developed within the IETF AVT working group
  - Provides stream signaling mechanisms
  - **No reliability mechanism**
  - Particular audio/video code to be used not mandated
  - Various standardized A/V formats
  - Provides ability to use standardized A/V format of choice
  - Adoption by mobile broadcast/multicast standards
    - 3GPP MBMS
    - 3GPP2 BCMCS (will be under consideration)

Streaming reliability

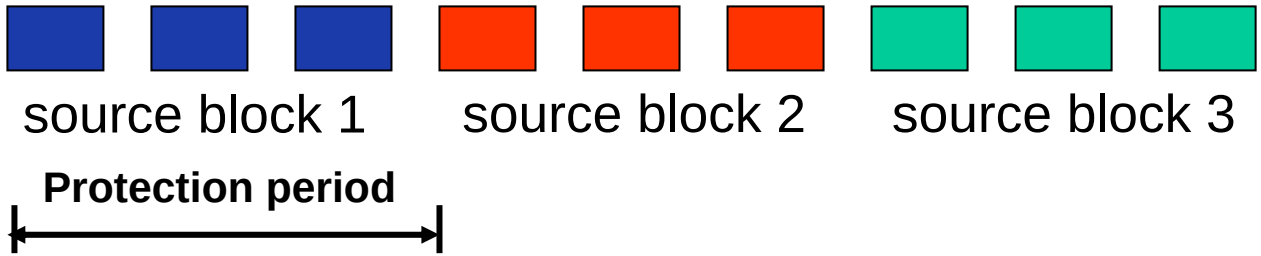
- **FEC streaming framework (FEC-SF)**
  - Developed within the 3GPP SA4 working group
  - Uses FEC building block (RFC3452)
  - Uses UDP as transport
  - Streaming format agnostic (works with RTP, MIKEY, etc.)
  - Allows concurrent protection of one or more streams
  - Adoption by mobile broadcast/multicast standards
    - 3GPP MBMS
  - Will be a BOF at upcoming IETF to consider new FEC wg based on the FEC-SF

RTP + FEC-SF

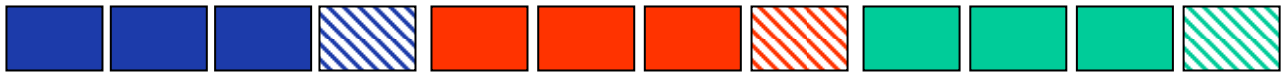

RTP
RFC 3550
Application-layer streaming protocol
FEC BB
RFC 3452
FEC-SF
FEC-protection for streaming protocol
Various FEC code specs in process
UDP

RTP/FEC-SF streaming sender

RTP stream (original)



FEC stream (sent)



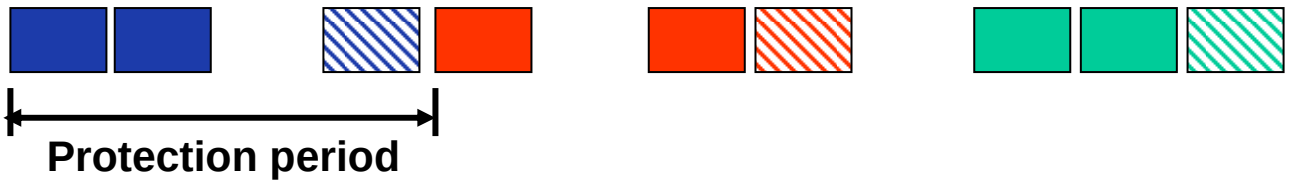
FEC encode each source block independently to generate repair packets from source packets

For each source block in sequence:

Send source packets first

Send repair packets after

RTP/FEC-SF streaming receiver



FEC stream
(received)

FEC decode each source block independently
from received source and repair packets

RTP stream
(recovered)

source block 1 source block 2 source block 3

Example of FEC scheme for FEC streaming

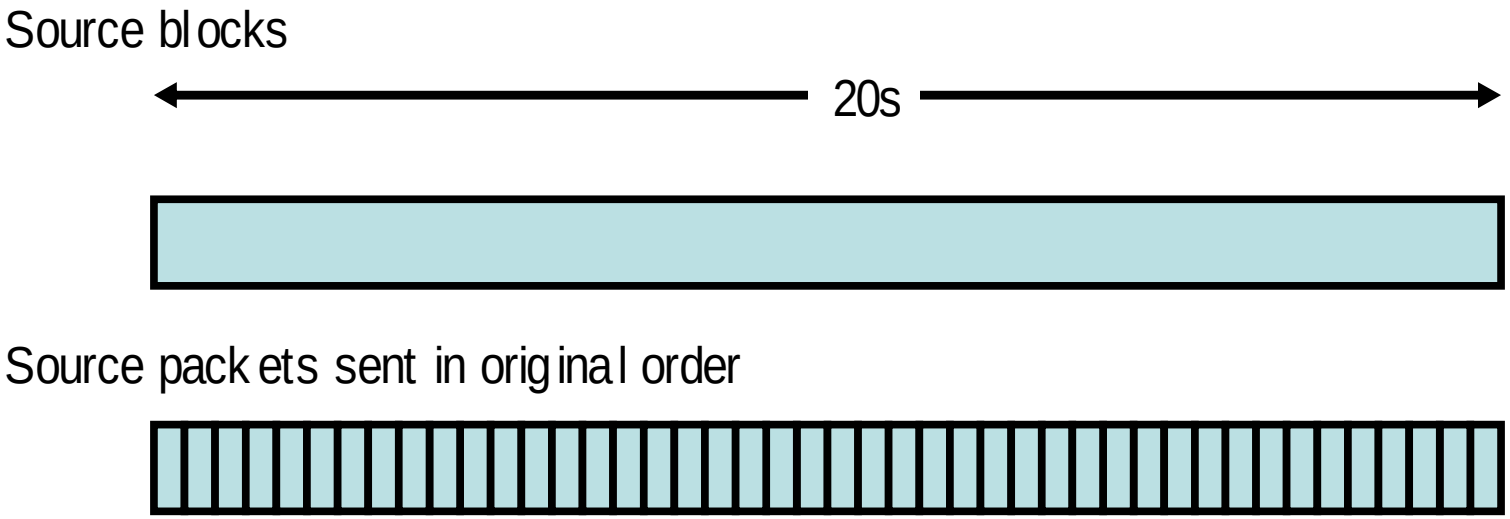
- **FEC Encoding ID 2**
  - There must be an RFC that describes the FEC scheme
- **FEC Object Transmission Information**
  - FEC Encoding ID 2
  - Symbol size in bytes
  - Maximum source block size in symbols
- **Source FEC Payload ID (appended to source packets)**
  - Source Block Number (2 bytes)
  - Encoding Symbol ID (2 bytes)
- **Repair FEC Payload ID (header of repair packets)**
  - Source Block Number (2 bytes)
  - Encoding Symbol ID (2 bytes)
  - Number of symbols in the source block (2 bytes)

FEC evaluation for 3GPP MBMS

Application-layer FEC for 3GPP MBMS

- **Operators insisted that:**
  - Only one application-layer FEC code be chosen
  - Chosen FEC code is mandatory to be supported on receivers for both file delivery and streaming
- **Primary candidates**
  - Reed-Solomon erasure codes
  - Raptor (R10)
- **Raptor (R10) chosen**
  - Operators got their way

Raptor (R10) streaming for MBMS



No interleaving

Protection period = 20s and media rate = 205Kbps

→ SBL = 512KB

FEC protection = 25% → Send 128KB of FEC data → 640KB EBL → 256Kbps data rate

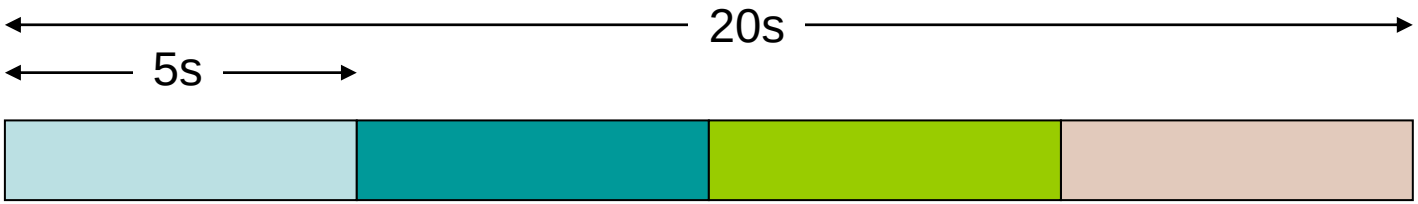
Protection period = 5s and media rate = 48Kbps

→ SBL = 30KB

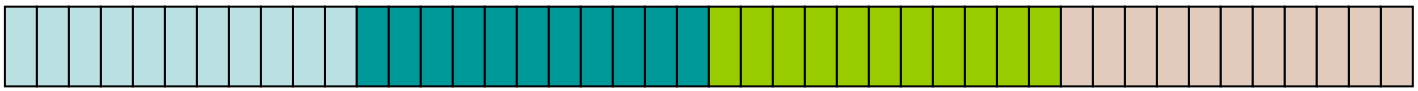
FEC protection = 33% → Send 10KB of FEC data → 40KB EBL → 64Kbps data rate

Reed-Solomon streaming proposal for MBMS

Source blocks



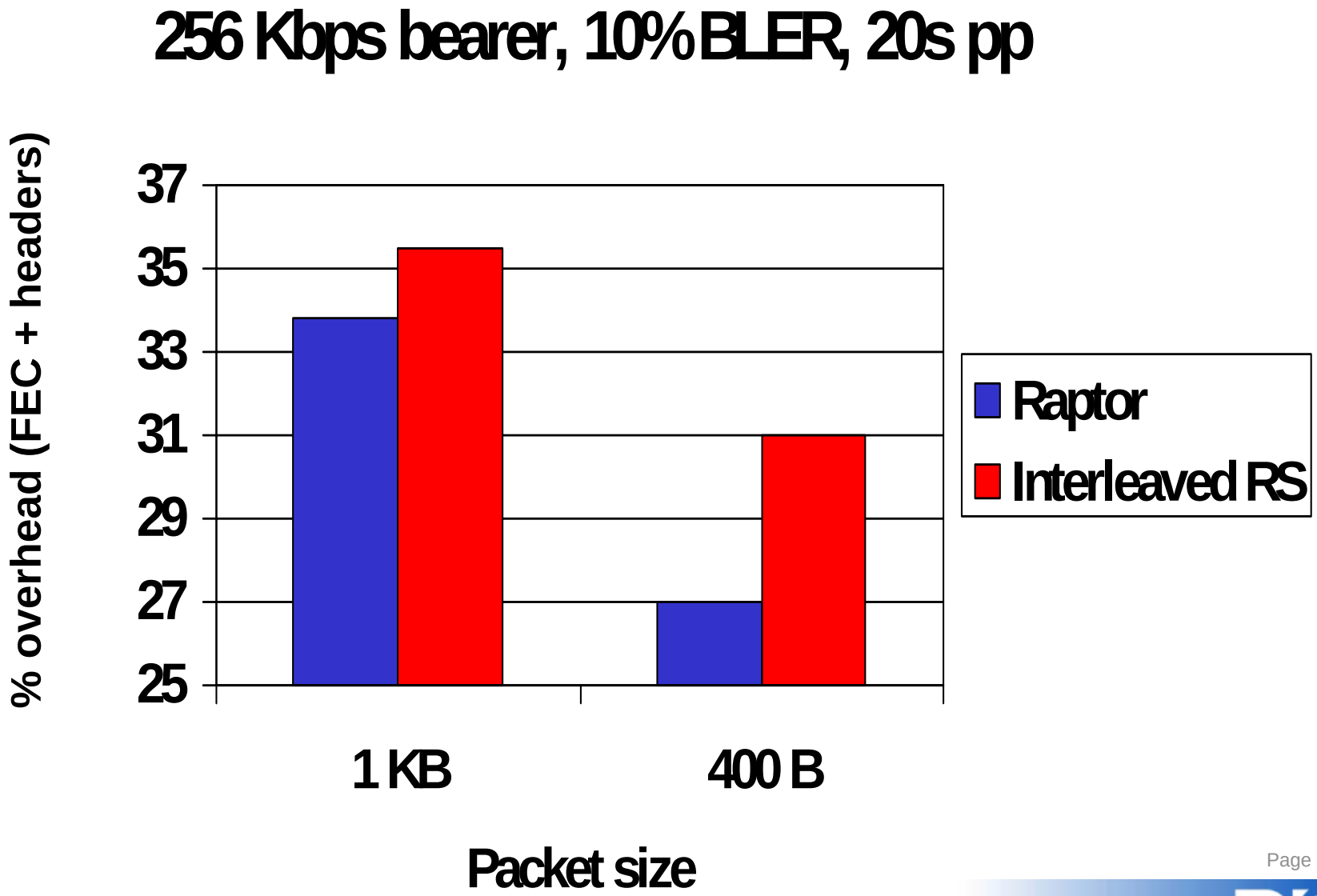
Source packets



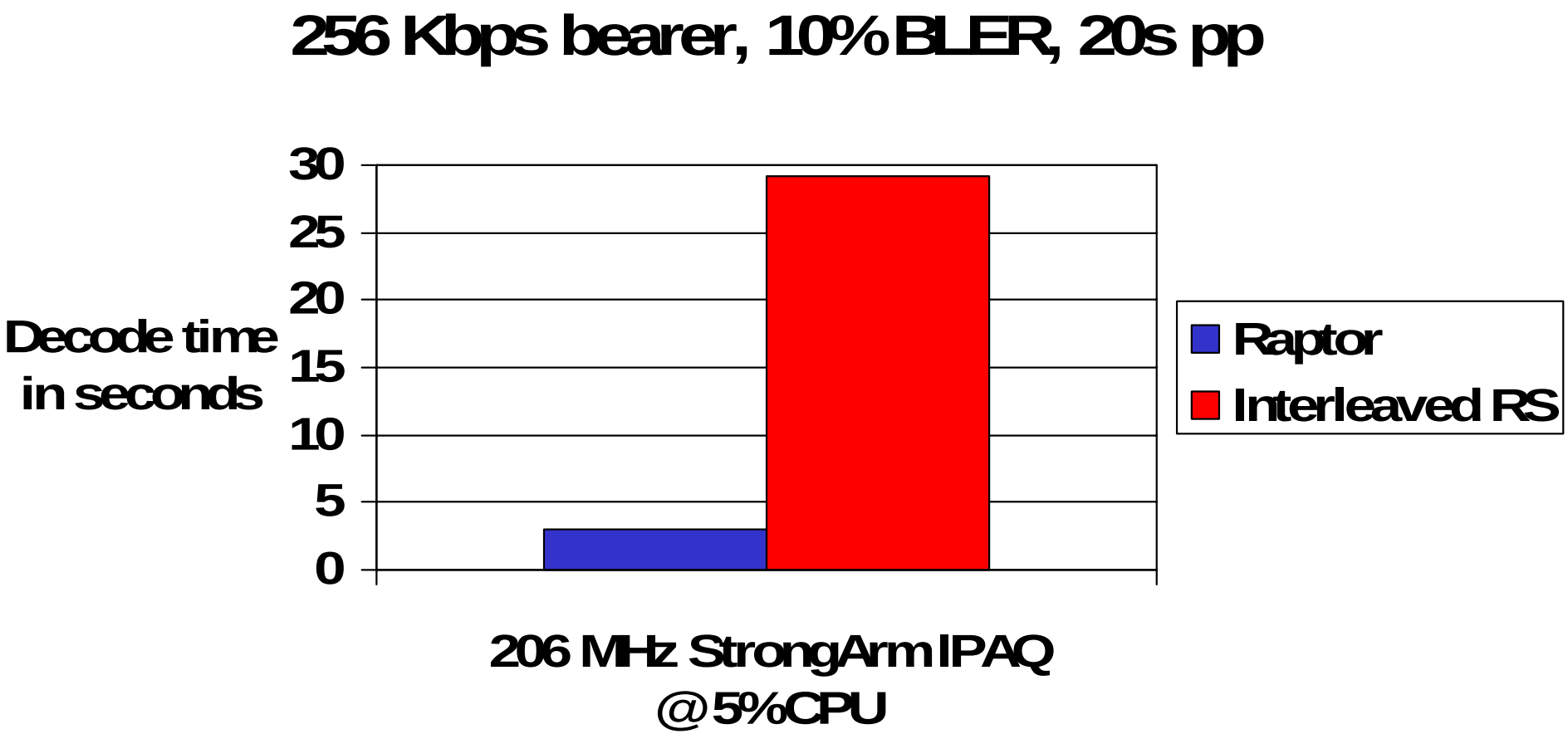
Source packets sent in interleaved order

Interleaving

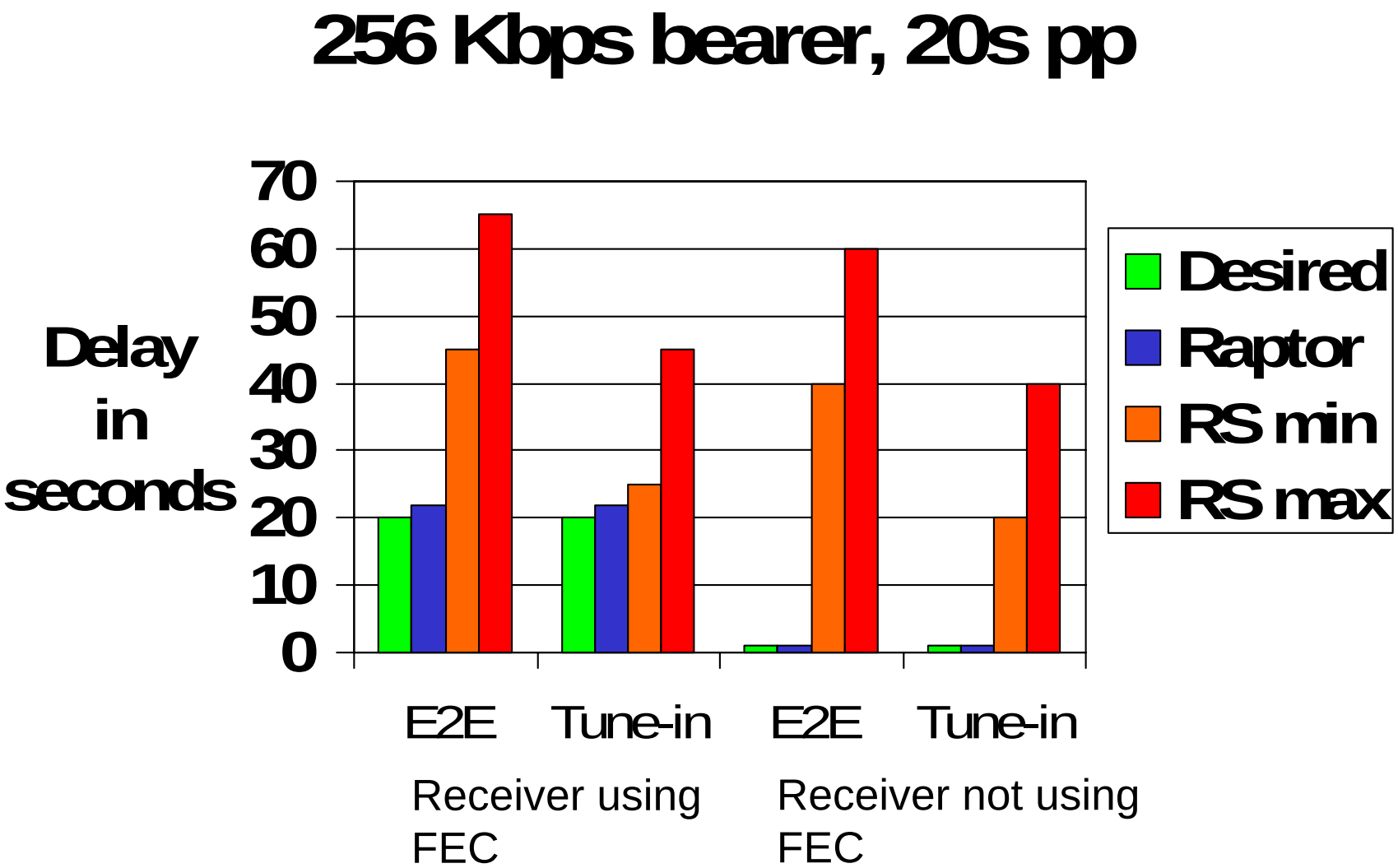
Raptor vs Reed-Solomon: MBMS streaming



Raptor vs Reed-Solomon: MBMS streaming



Raptor vs Reed-Solomon: MBMS streaming

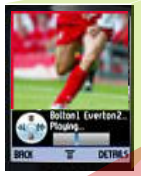


MBMS stream bundling

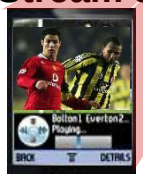
Transmitter:

Stream 1

Stream 2



Stream 3



FEC Source blocks

FEC repair data

Multiplexer+ FEC

Streams FEC protected as a bundle – Highest quality delivery

Direction of transmission

Receiver:

Lost packets

De-Multiplexer

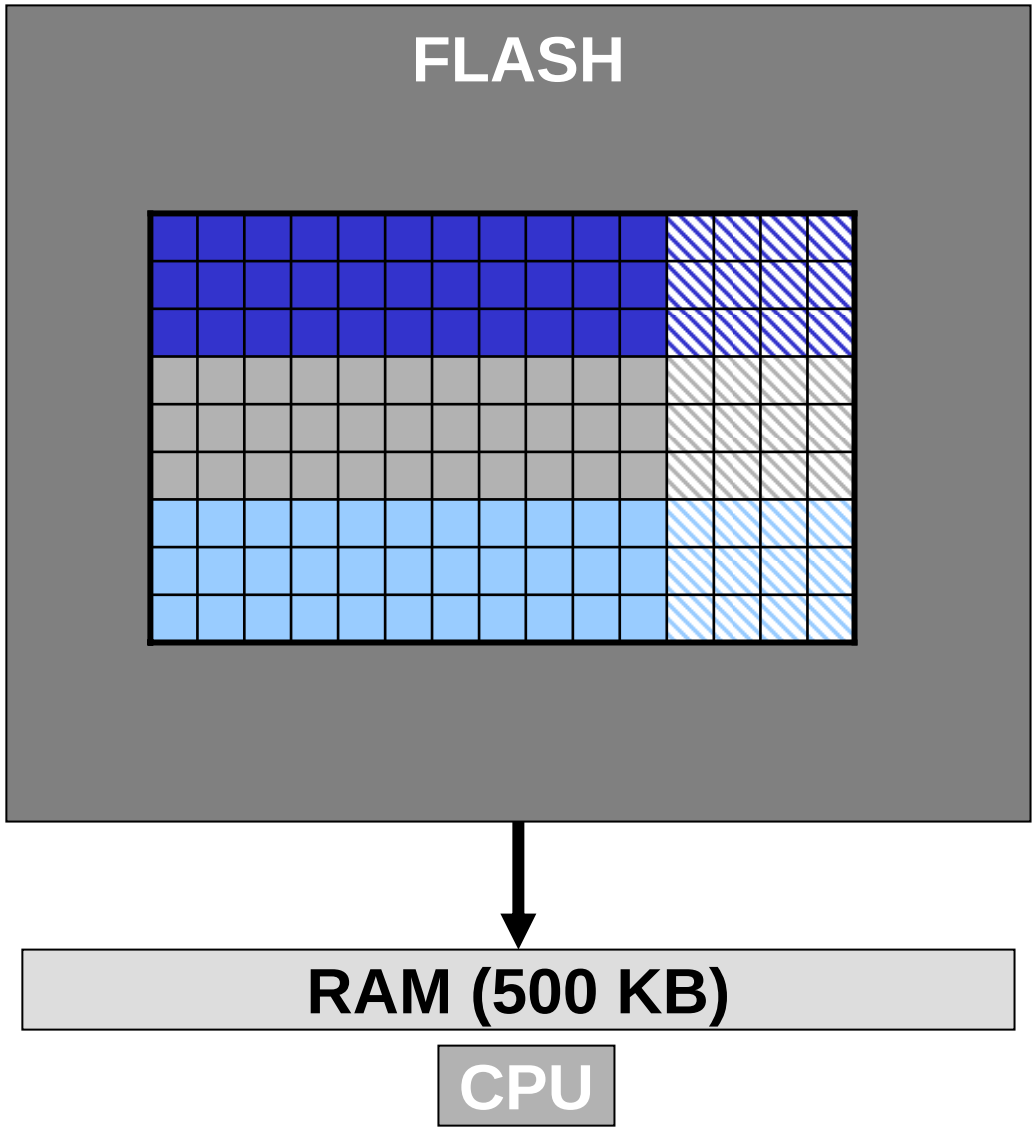
FEC Decoder

All streams available for viewing all the time – Instant channel switching

Stream selector

Play out

Raptor (R10) file delivery for MBMS



RAM requirements:

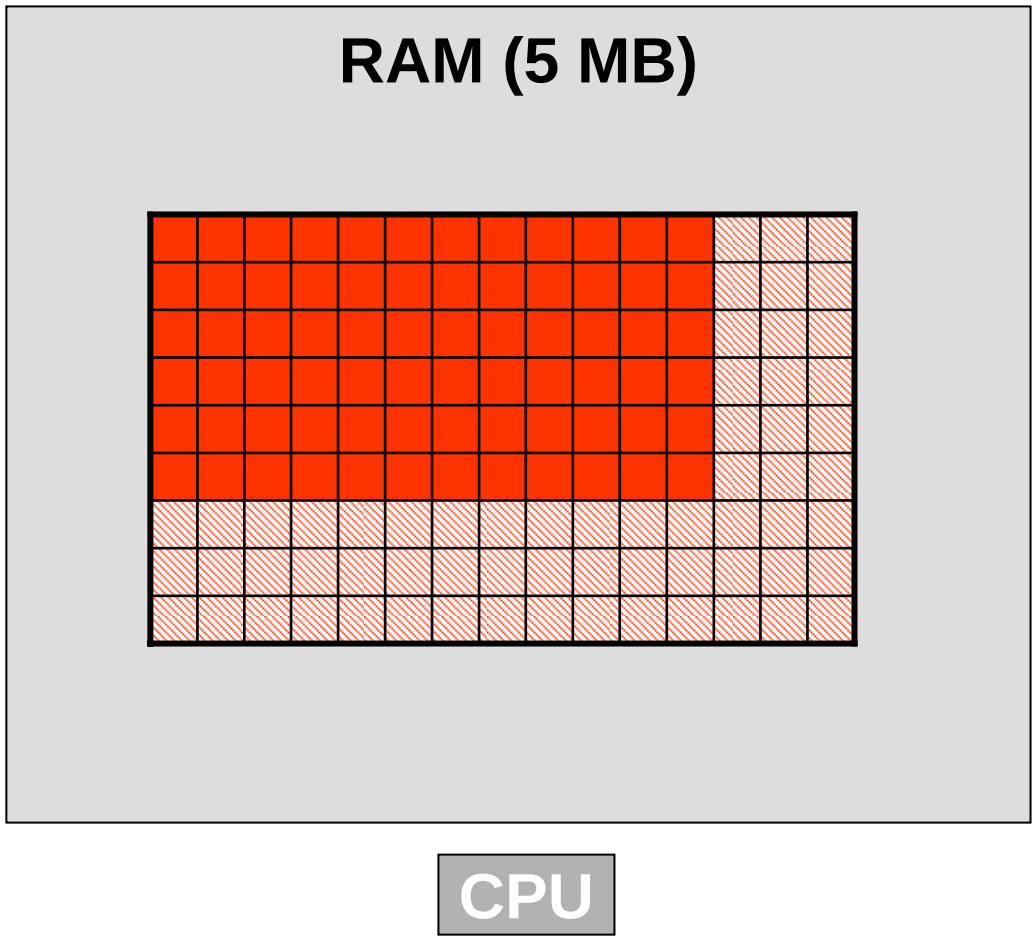
- A fraction of the file size
- Example
  - 4 MB file
  - 500 KB of RAM

•Decoding completed in one sweep from beginning to end

- File available from beginning during decoding

Reed-Solomon file delivery proposal for MBMS

2D Reed-Solomon interleaving



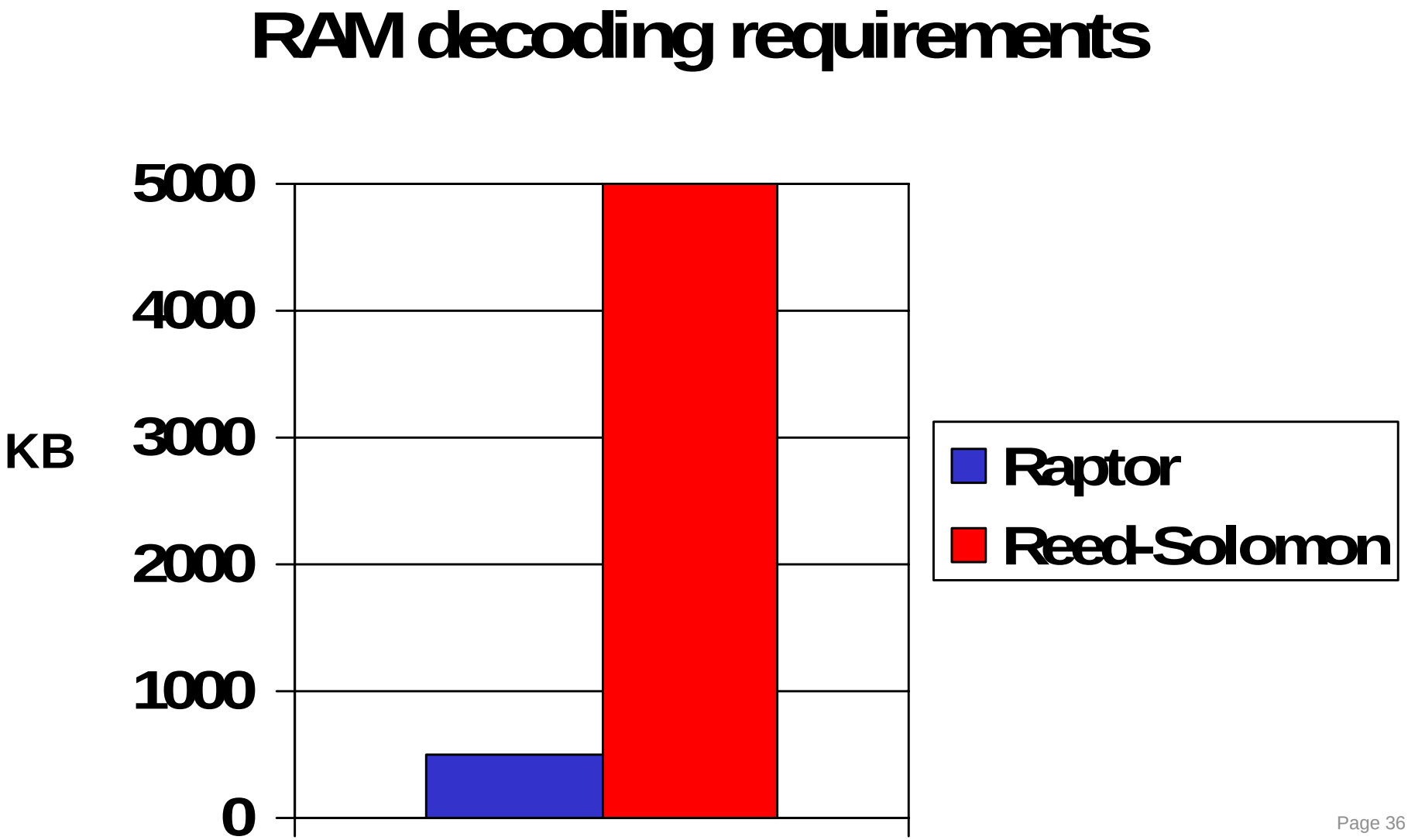
RAM requirements:

- Entire file size
- Example
  - 4 MB file
  - 5 MB of RAM

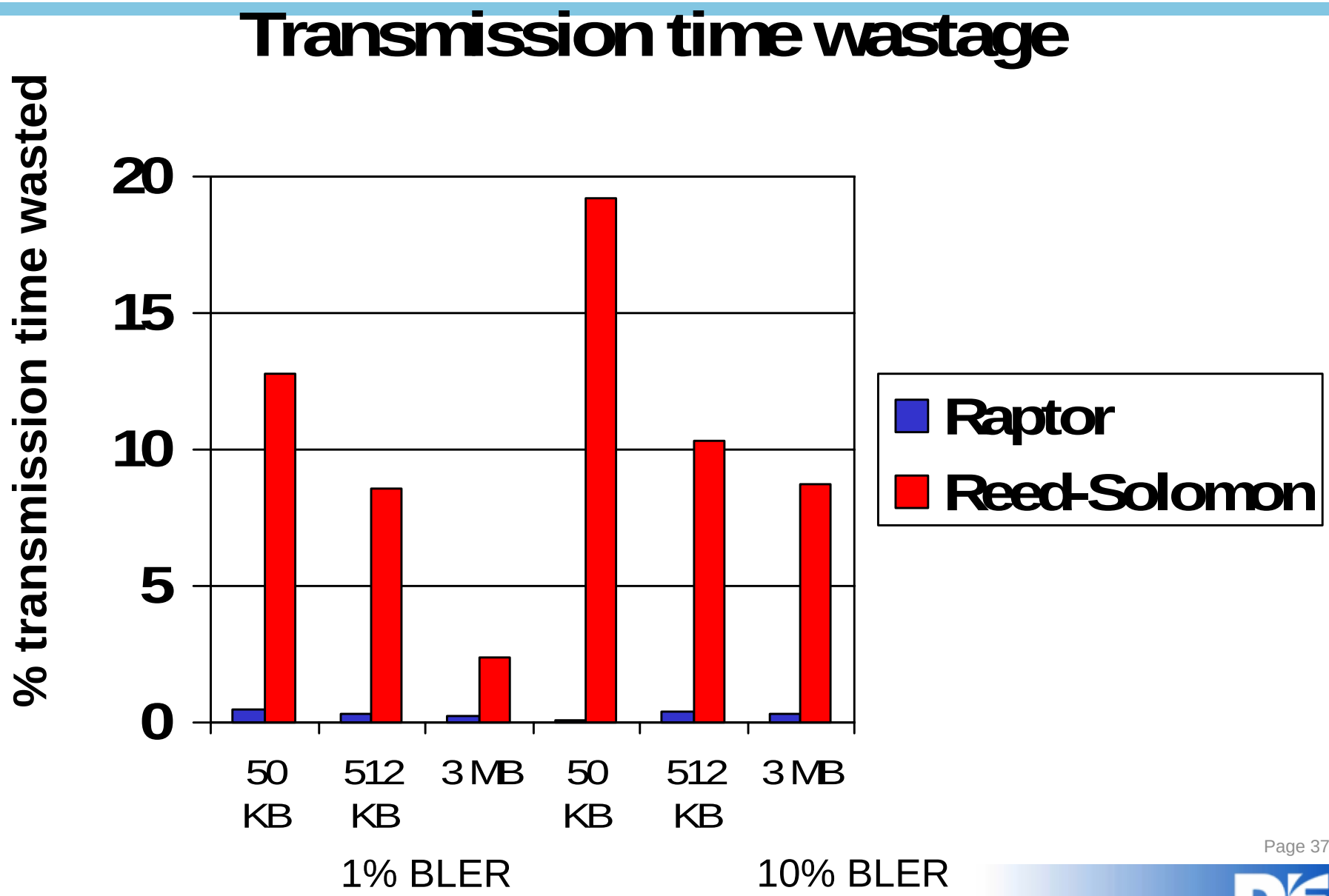
•Decoding requires random access to received FEC data

- File available only after complete decoding

Raptor vs Reed-Solomon: MBMS file delivery



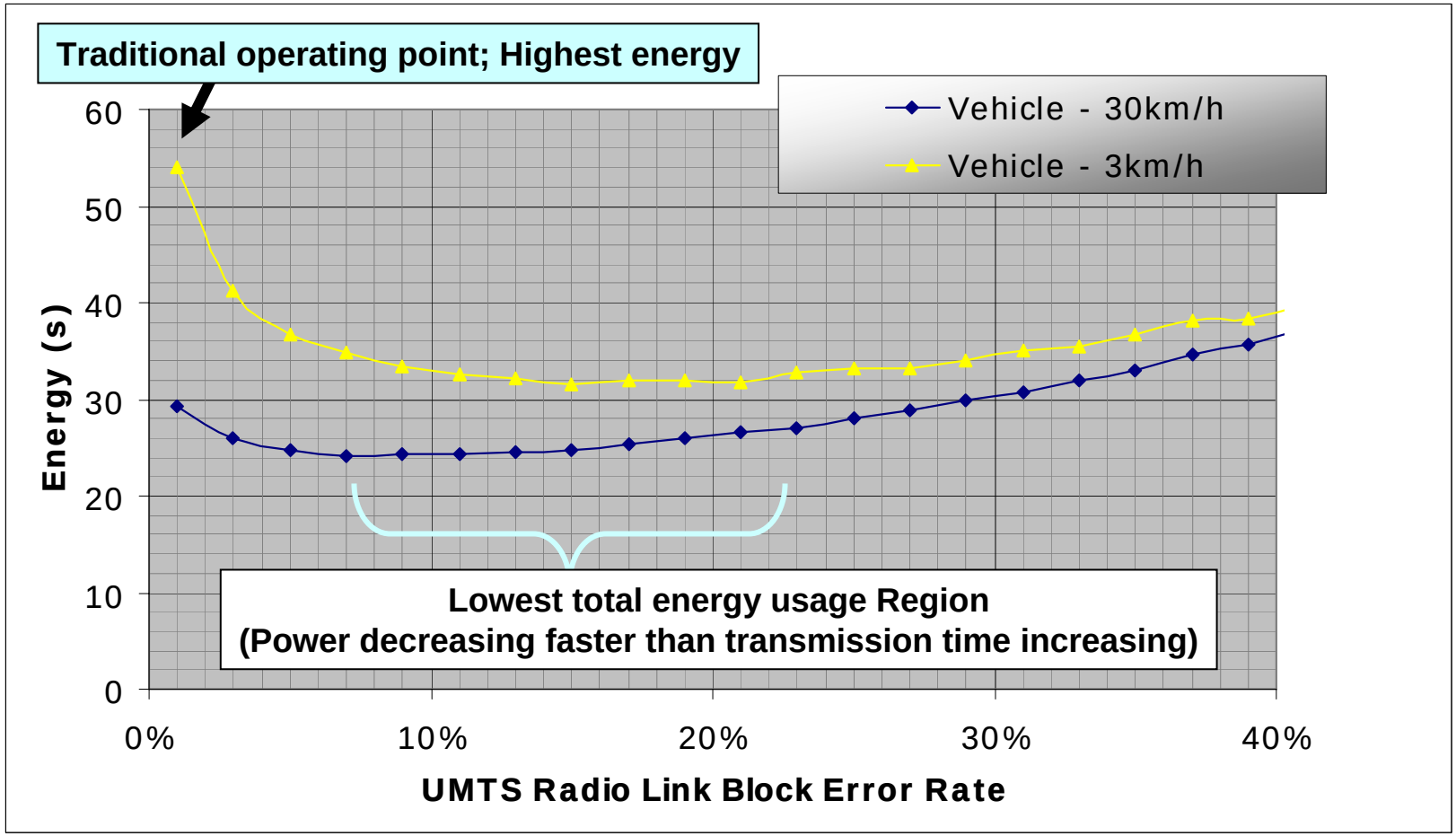
Raptor vs Reed-Solomon: MBMS file download



3GPP MBMS resource usage savings

- **Joint work with Vodafone**
- **Methodology:**
  - Choose power for MBMS stream (Eb/No)
  - Determine corresponding BLER from TR 25.803
  - Determine time needed for file download to 99% of the users using Ideal codes
  - MBMS resource usage = power x file delivery time
  - Repeat for different power levels to find minimum MBMS resource usage

Example: Equivalent Capacity (UMTS) with Lower Transmission Energy by incorporating DF Raptor



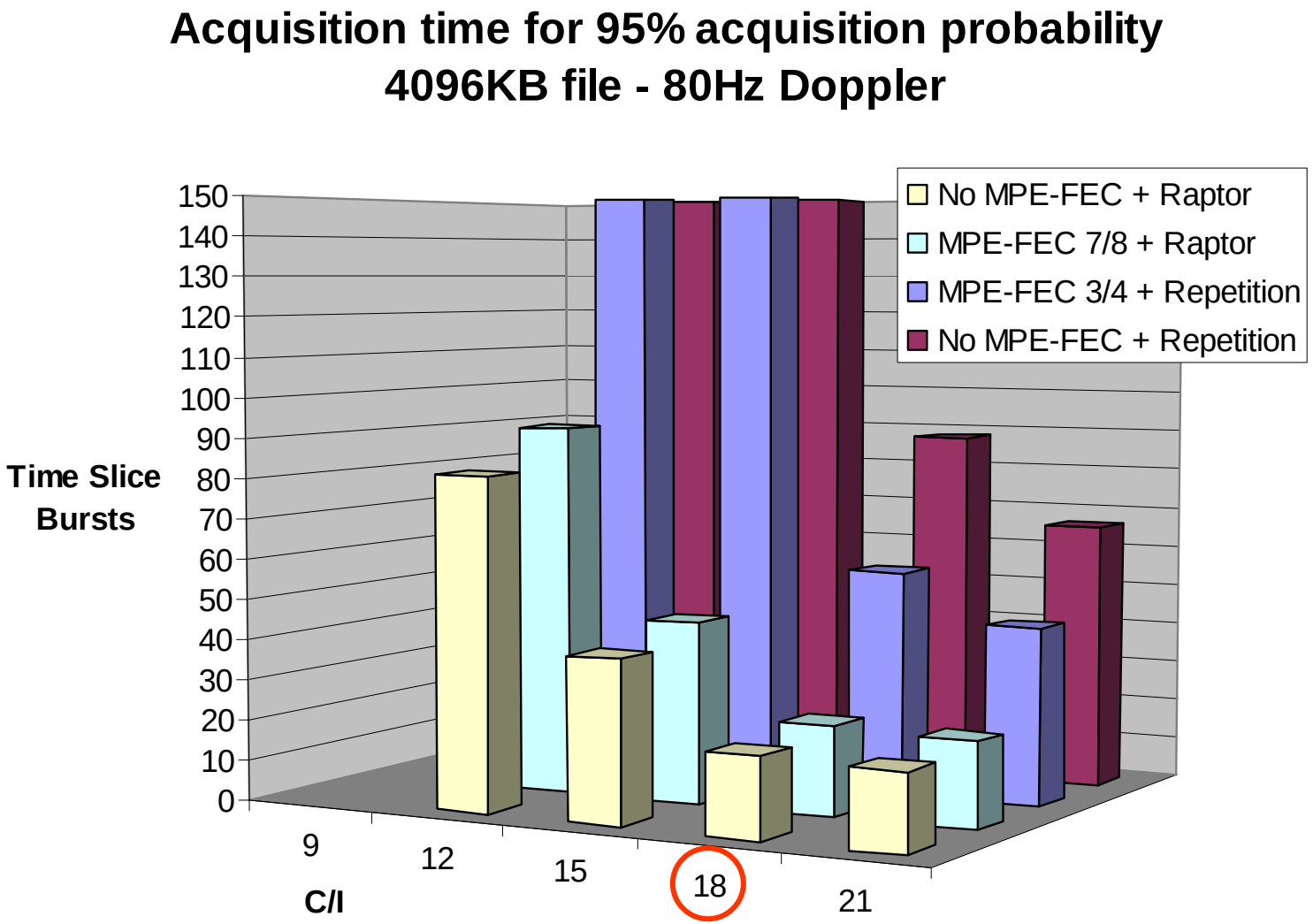
- 256kbit/s channel, Geometry=-3dB, 2MB file
- DF Raptor code at application layer

FEC evaluation for DVB-H IPdatacast file delivery

Application-layer FEC for DVB-H IPdatacast

- **Burst delivery model**
  - 250 KB of data burst for one second each 10 seconds
  - Application-layer FEC for streaming more difficult
  - Application-layer FEC considered only for file delivery
- **MPE-FEC already exists at link layer**
  - Reed-Solomon erasure code protects packets
  - Applied to fixed-sized bursts of data at link layer
  - Typically implemented as an ASIC
  - A few fixed rates available (including turned-off = rate 1)
- **Almost all operators wanted**
  - Only one application-layer FEC code be chosen
  - Chosen FEC code is mandatory
- **Raptor (R10) chosen**
  - Operators almost got their way (exception: not mandatory)

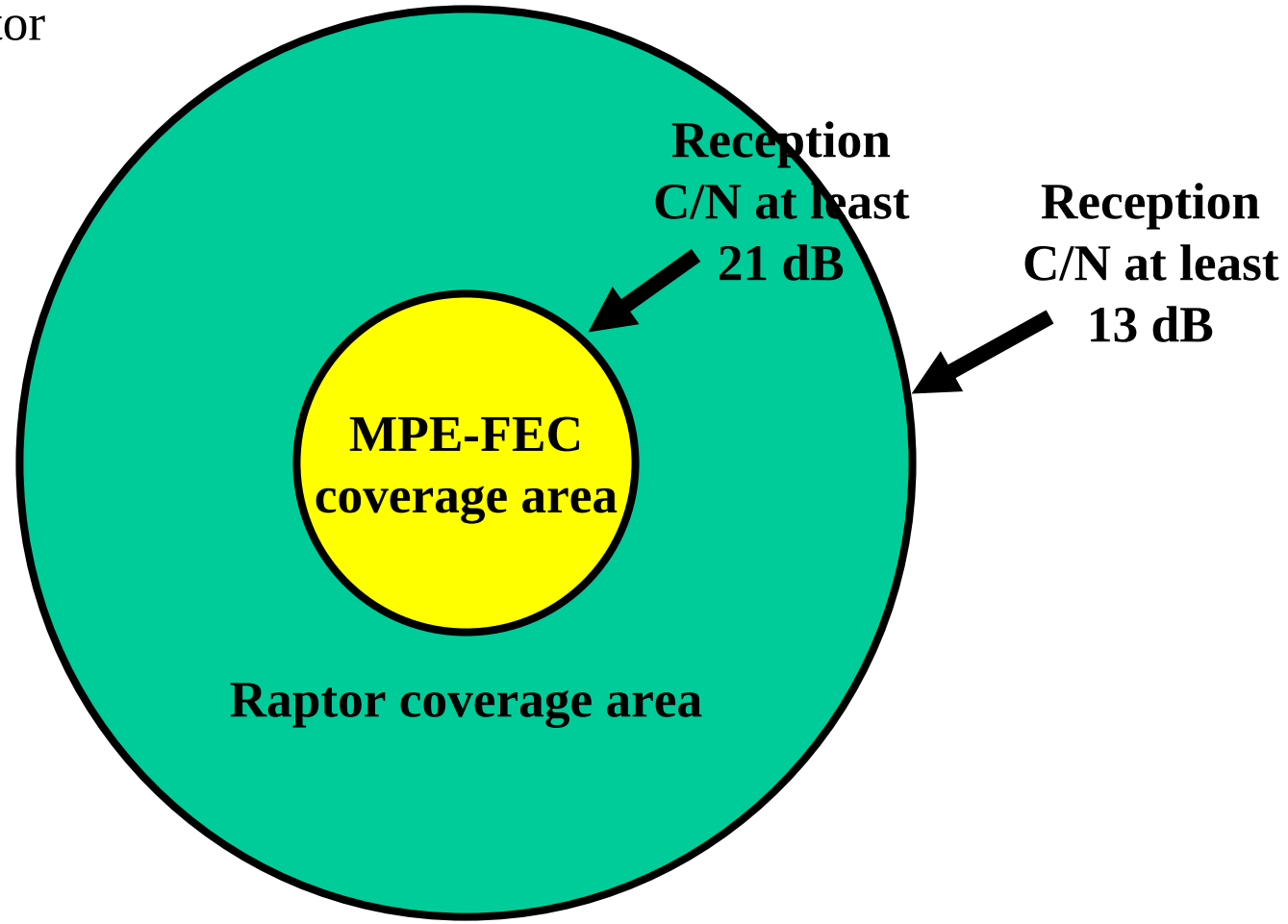
DVB-H file delivery example



Previously considered “edge of coverage”

Increased Range via Reduced Link Margin

More coverage offered by Raptor



Raptor advantages for Mobile Broadcast/Multicast

- **Increased reliability**
- **Increased range**
- **Increased throughput**
- **Increased radio resource usage efficiency**

Thank You !