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Improving Robustness, Throughput , Latency and Channel Awareness in Software Defined Radios

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Overview

- Common wireless communication systems performance targets:
  - Throughput
  - Latency
  - Link Reliability: availability, robustness against interference
- Extra SDR challenges
  - Cannot take advantage ASIC speeds
  - Be cognitive and adapt with the channel
- Is there a secret sauce that we can use?
- Yes! The **Automatic Repeat reQuest (ARQ)** mechanisms
- Counterintuitive because we all “know” ARQ increases latency significantly and decreases throughput . But is it true?

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Common ARQ schemes

- WiFi ARQ
  - Compensates for varying signal strength but also collisions
  - Essential for good operation
  - Stop-and wait – no new packet sent until ACK received for current
  - Selective Repeat for 802.11n aggregated packets
  - Uses multiple retries on different modulations → high latency → typically delay sensitive services (e.g. voice) use a scaled down retry scheme
  - The retries may worsen congestion

- TCP ARQ
  - Get a single ACK for a number of sent of packets (TCP window)
  - Selective Repeat ARQ
  - Multiple retries
  - High latency because of ACK latency
  - Designed to guarantee delivery even under network congestion
  - Not designed to deal with random PHY packet loss

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Common ARQ schemes

- 802.16d (WiMAX-d)
  - ARQ was considered non-important → not mandatory
  - ARQ used a TCP-like scheme → very high latency
  - TCP ARQ could kick in before 802.16 ARQ → a lot of wasted bandwidth
  - Nobody used ARQ → larger link margins

- LTE and 802.16e (WiMAX-e)
  - Lessons learned from 802.16d:
    - ARQ is important for link budget
    - ARQ feedback must be fast
  - Two-tier ARQ:
    - Hybrid ARA (HARQ)
      - Fast feedback
      - Same modulation
    - Standard, TCP-like ARQ

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New ARQ scheme

- Immediate ARQ feedback
  - For DL, schedule ARQ feedback in the UL in the same frame
  - For UL, BS knows immediately anyway
- Selective Repeat
  - No wasted bandwidth
- Single retry
  - At most one extra frame
- Use lower modulation and/or coding to ensure delivery
  - Improves PER by $>10^4$

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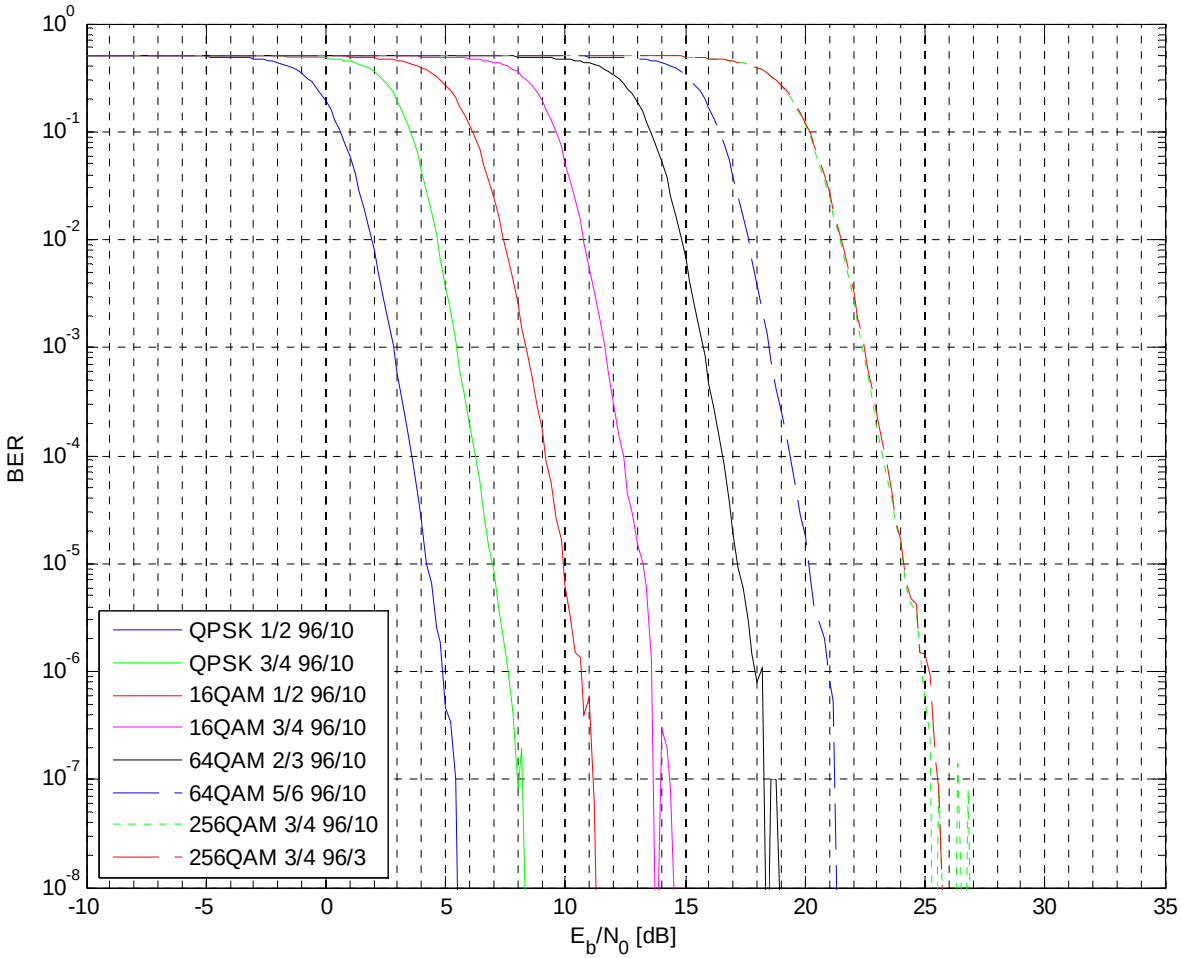
Retry Modulation: same or lower?



Lower modulation or coding → >10^4 BER improvement

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Is latency really an issues with ARQ?

- YES, if using multiple retries (WiFi scheme)
  - 10 retries means 10x the latency
- YES, if there is no explicit NACK (WiFi scheme)
  - Transmitter waits for time-out to infer packet did not arrive at destination
- YES, if not using fast feedback (TCP-like scheme)
  - Selective-repeat is nice but let's get that feedback immediately
- **NO, if done properly**, e.g. in a TDD system
  - Send packet in frame K, get feedback in the same frame
  - If needed retry in frame K+1 than stop
  - Guarantee retry success by lower modulation and/or coding

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Latency depends on implementation

Measurement	WiMaxD	WiMaxE/LTE	Redline
Average DL delay no ARQ	**2 frames**	**2 frames**	**0.5 frames**
Average DL delay with ARQ	**15-20 frames**	**6 frames**	**1.5 frames**
Average UL-RTP delay no ARQ	**3 frames**	**3 frames**	**1.5 frames**
Average UL-RTP delay with ARQ	**15-20 frames**	**6 frames**	**2.5 frames**

WiMax frame size: **5/10/20ms**
LTE Frame size: **2ms**
Redline frame size: **2…20ms**

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Can ARQ improve throughput?

- **YES**, if combined with adaptive modulation:
  - Single retry on a lower modulation that boosts packet error rate (PER)
  - Push principal modulation and coding as high as possible relying on retries to cover for increased PER
  - Switch to a lower modulation and coding rate only when the bandwidth loss to retries exceeds the bandwidth that would be lost if switching to a lower PHY modulation and coding, i.e. if:

$$T_1 \cdot (1 + PER_1 \cdot T_2) > T_3$$

Where:

T_1 = time it takes to send the packet at main modulation and coding
T_2 = time it takes to send the packet at retry modulation and coding
T_3 = time it takes to send the packet at a lower modulation and coding

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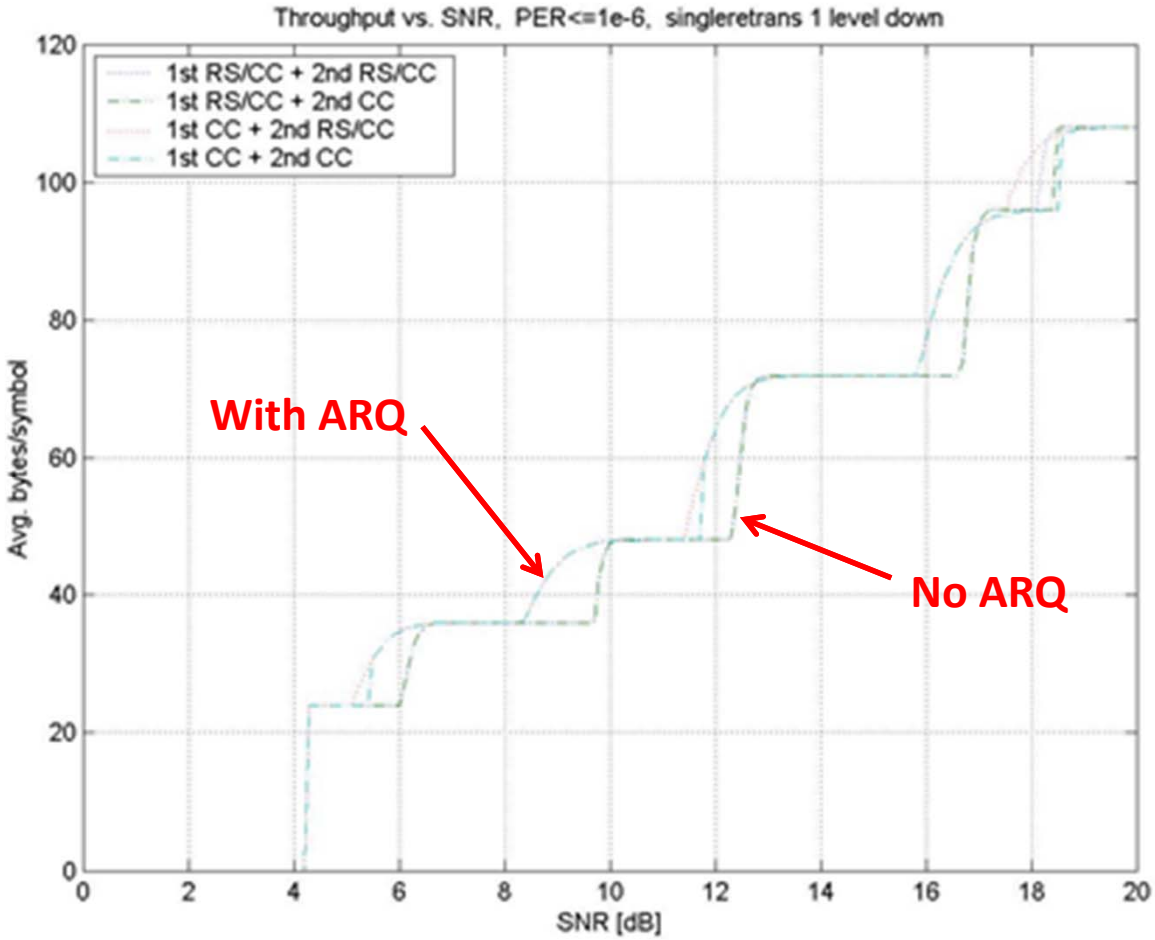
Can ARQ improve throughput?



Yes, by allowing a higher PHY rate!

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Can ARQ improve link reliability

- YES, because it can be more aware of the channel
  - PER on main modulation and coding can run > 1% and still maintain overall PER < 10^{-6} dues to the retry
  - → can easily sense when link worsens way before it becomes critical
- YES, because it can eliminate random over-the-air errors

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Do we really need such complex ARQ?

- Why not use a better channel coding?
  - For same reasons file systems have error recovery mechanisms despite having Error Correcting Codes (ECCs) at physical level
- TCP or higher layer protocol (for UDP) will ensure anyway reliable delivery
  - TCP will interpret packet loss as a sign of congestion and it will lower the throughput to reduce congestion → very low throughput
  - Many UDP-based protocols actually brake when placed in high packet-loss networks
- Why not use adaptive modulation?
  - Proposed ARQ lowers modulation and/or coding only for retries
  - It is not worth lowering modulation for thousands of packets following a random error
  - However it is worth lowering modulation just to ensure that random error does not cause end-to-end packet loss

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Questions?

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