Adaptive Modulation and Coding for Reliable Vehicular Real-Time Communication

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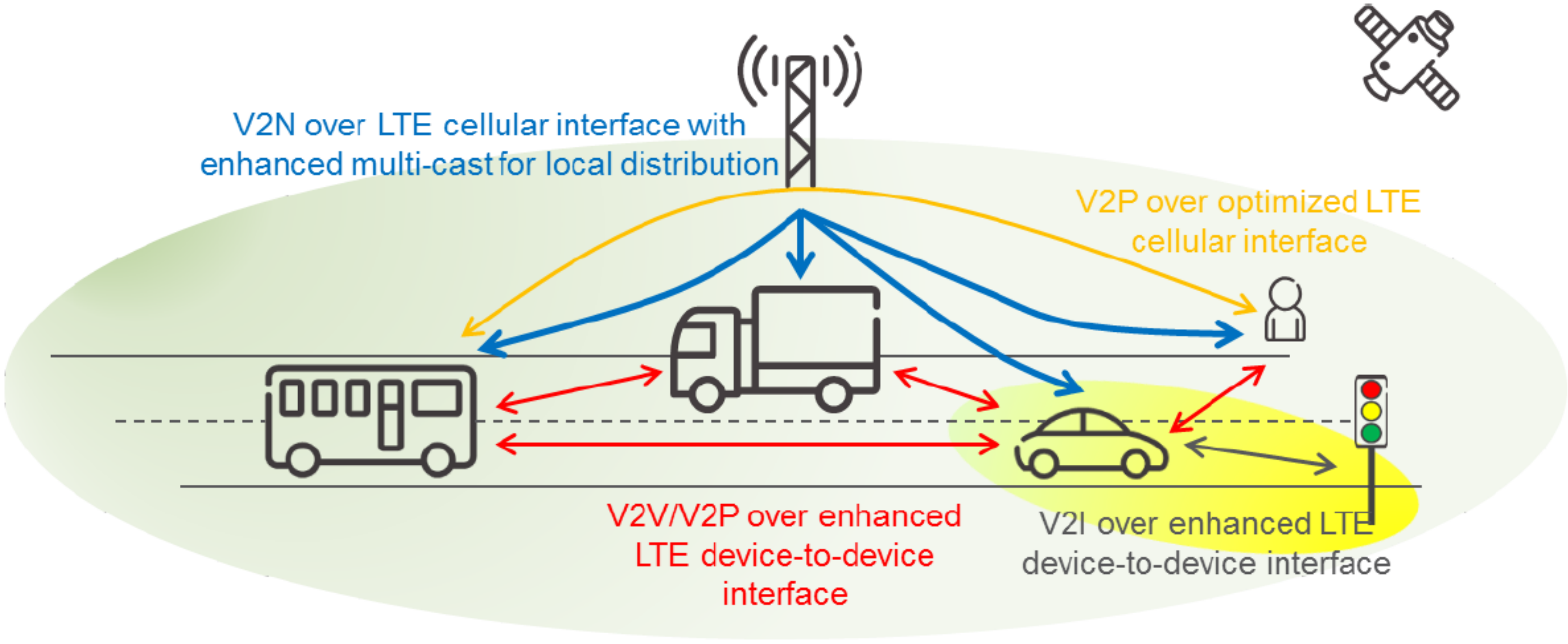
25. VDE/ITG Fachtagung Mobilkommunikation
- 5G Lösungen und 6G Ausblick -

Motivation



Source: Blasco et al. 3GPP LTE enhancements for V2V and comparison to IEEE 802.11p, 2016

- Vehicle to Vehicle
  - Advanced traffic view, collision warnings, …
- Vehicle to Infrastructure
  - Speed limit, traffic light timings, …
- Vehicle to Pedestrian
  - Pedestrian announcements, collision warnings, …
- Vehicle to Network
  - Route optimizations, …

(Adaptive) Redundancy

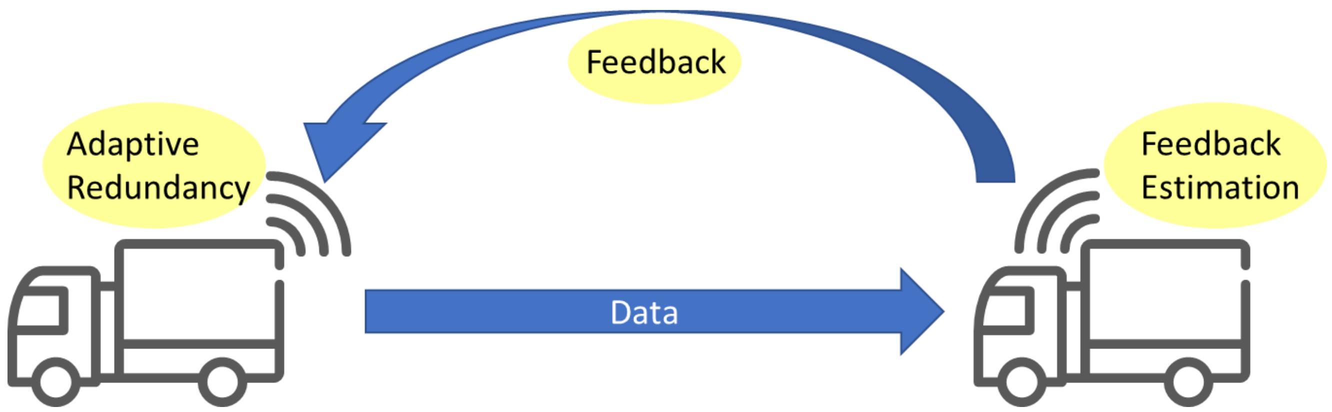
Why not use (most) robust redundancy all the time?

- Redundancy requires additional resources
- Resources limited for existing communication systems
- Redundancy reduces amount of possible transmissions

➔ Reduces amount of satisfied users

Use lowest "acceptable" redundancy

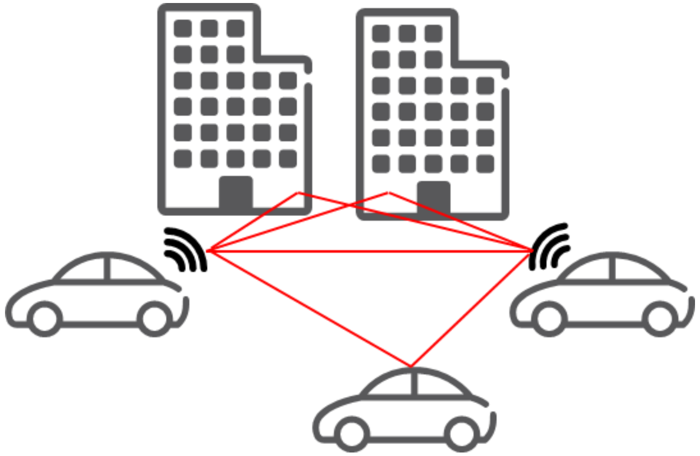
➔ Redundancy adaption (Adaptive Modulation & Coding)



Wireless Channel Properties / **Models**

Multipath propagation

- Signal propagates on multiple paths
- Arrival at different times
- Superposition of all paths



Shadowing

- Signal is attenuated by objects
- None line-of-sight paths

Wireless Channel Properties / **Models**

Path loss

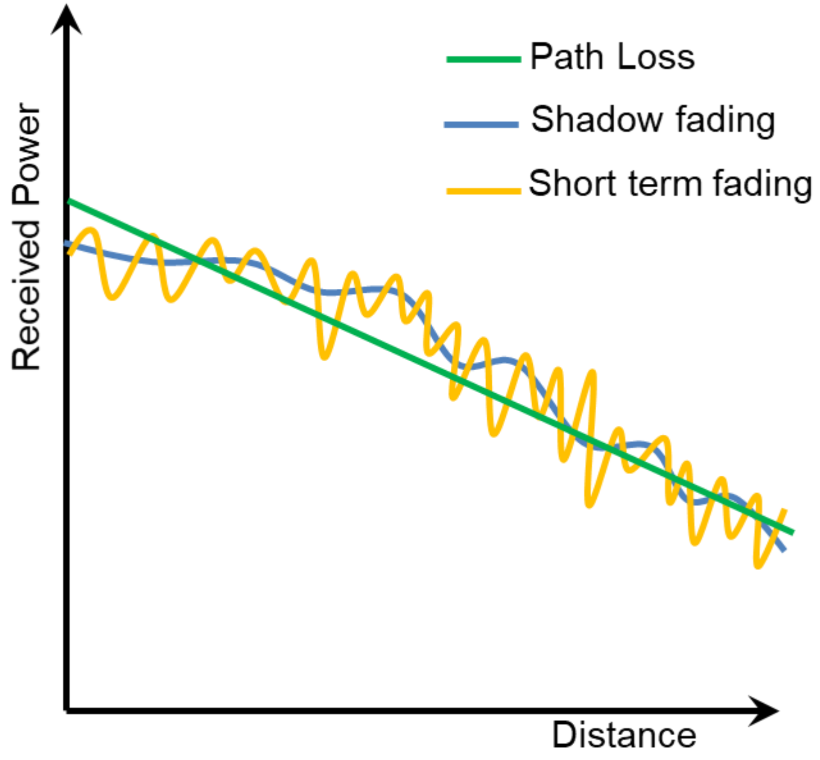
- Received power decreases with increasing distance

Shadow fading

- Signal attenuated by objects

Small scale (short term) fading

- Superposition of all received multipaths components



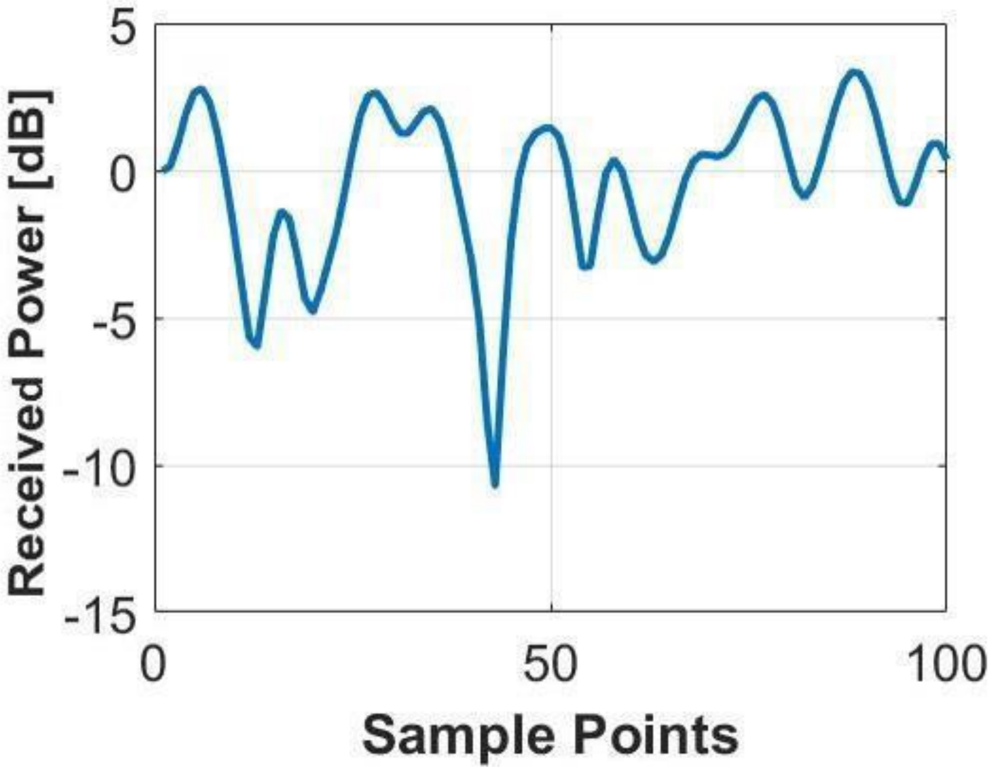
Wireless Channel Properties / **Models**

Channel properties change over time

- Movement of sender and receiver
- Movement of obstacles

Can be modelled by stochastic process

- Probability distribution
- Autocorrelation
- Described by parameters (Doppler shift, ...)



Minimum S(I)NR

Channel properties change over time

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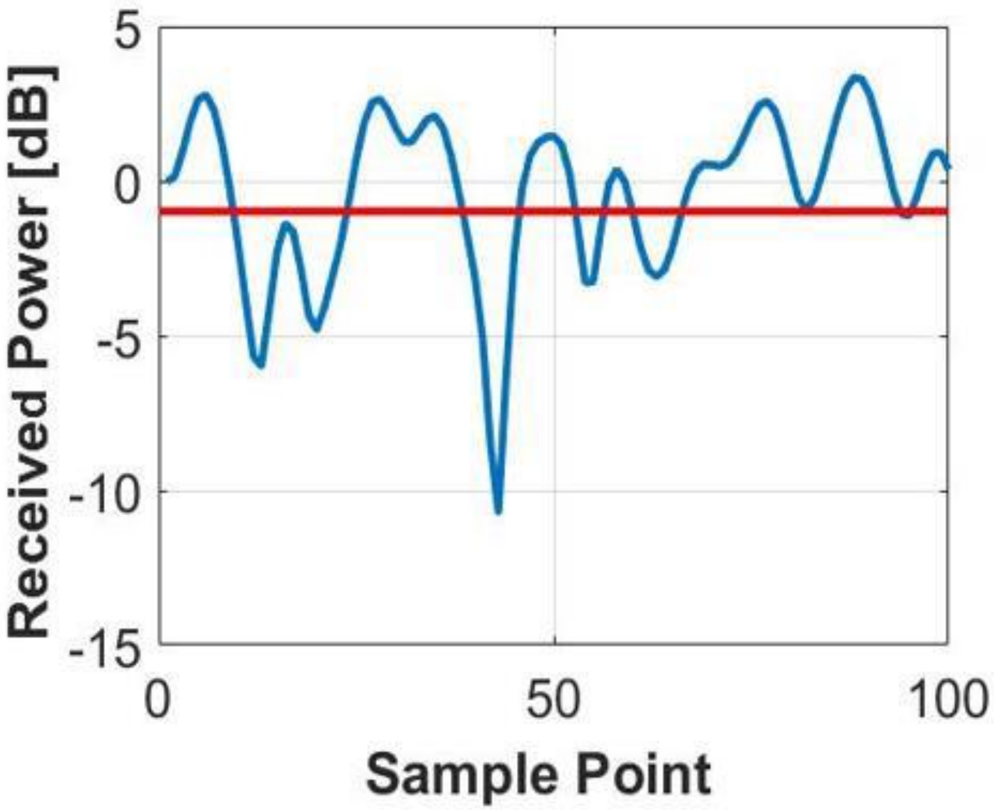
Assumption: Interference free V2V Sidelink resources through network-based coordination

- Received signal strength determines reliability



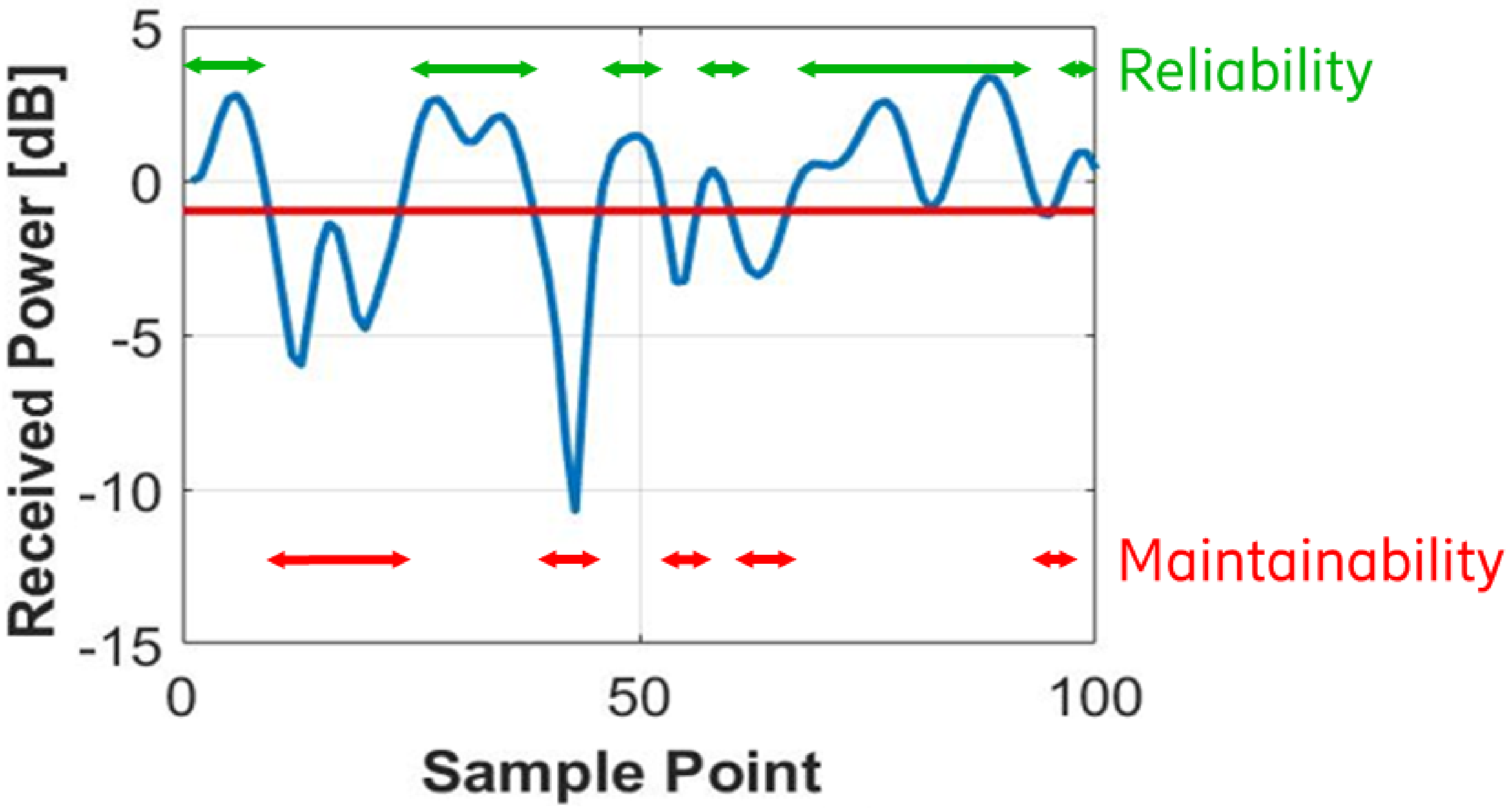
Terminology[1]: Reliability and Maintainability

Reliability

- Probability of duration of failure free performance

Maintainability

- Probability of duration of restoration



1) International Electrotechnical Commission (IEC) IEC 60050-192:2015 – International electrotechnical vocabulary - Part 192

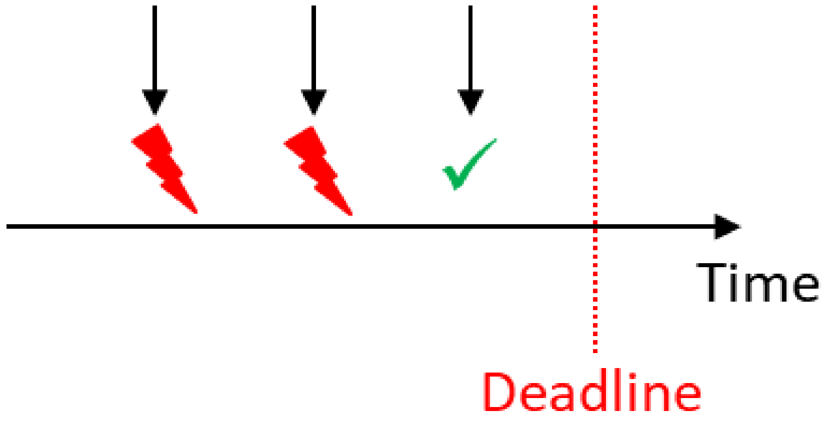
Impact of Fading Duration

Transmission losses may not affect application availability

- System requires successful transmission in certain time
- Higher layer retransmissions can mask lower layer losses
- Retransmissions require additional time

Important for system availability

- Fading duration ➔ channel maintenance time
- No failure, if packet arrives before deadline
- **System "failure" occurs, if channel fades for too long**



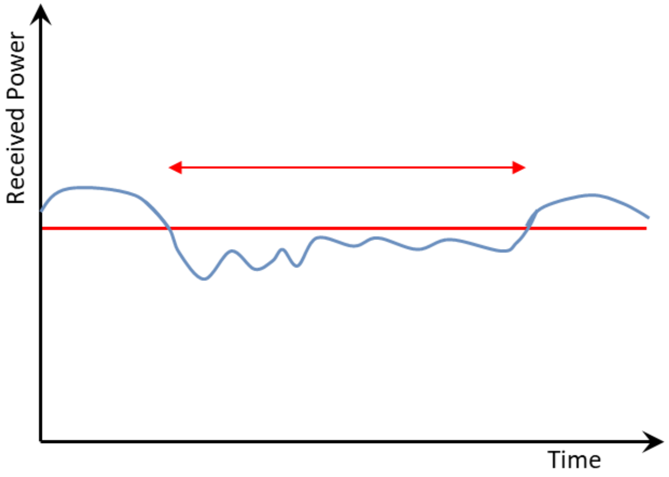
Impact of Fading Duration

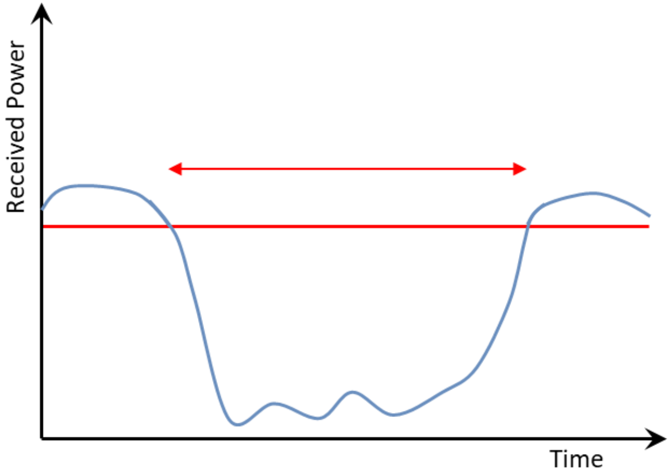
Two state model represents channel

- `Better than required' and `worse than required'
- State sojourn time

Fading severity not that important

- Packet loss expected if received power below threshold





Duration Modelling: 2-state Markov Chain

Fading processes modelled as Markov processes[1)]

- Next state depends only on current one: **2 parameter**

Fading modelled as Markov chain

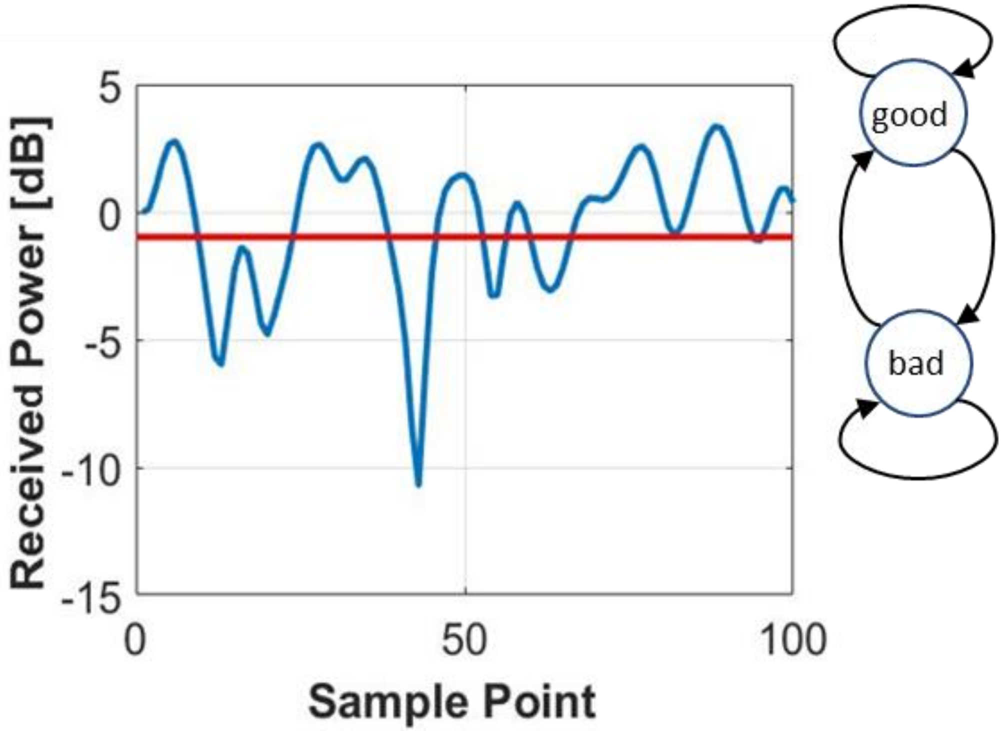
- “good”: above threshold
Wang e
- “bad”: below threshold

Discrete time

- Resources in LTE/5G discretized (Transmission Time Intervals (TTIs))
- Fading duration of several TTIs

Failure probability

- CCDF of sojourn time of “bad” state

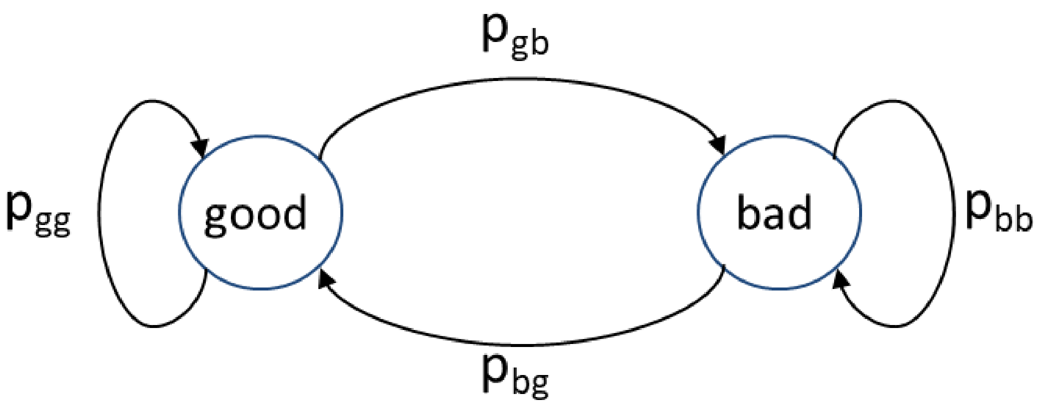


1) Wang et al., Finite-state markov channel - a useful model for radio communication channels, 1995

Duration Modelling: 2-state Markov Chain

- State transition refers to crossing of threshold level
- Transitions to adjacent states only ➔ **Level crossing rate method**

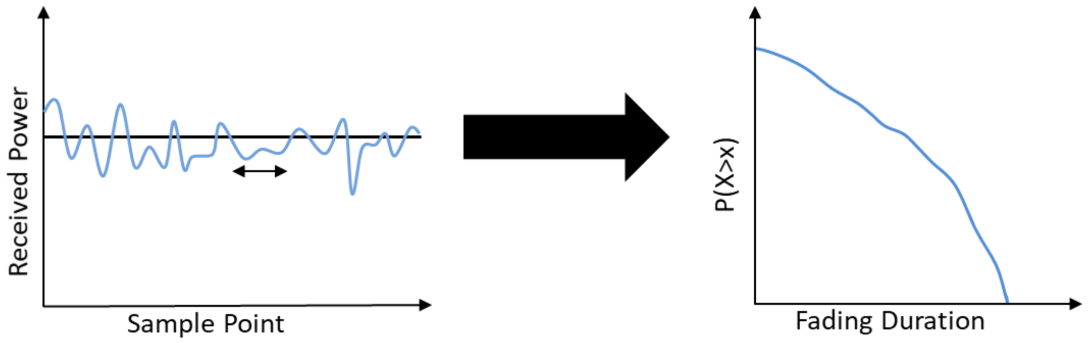
$$p_{gb} = \frac{N(\Gamma)}{\pi_g \cdot R_s}$$
$$p_{bg} = \frac{N(\Gamma)}{\pi_b \cdot R_s}$$
$$p_{bb} = 1 - p_{bg}$$
$$p_{gg} = 1 - p_{gb}$$
$$\pi_g = 1 - F(\Gamma)$$
$$\pi_b = F(\Gamma)$$



- R_s: Sampling rate, Γ : Threshold, ***N*(Γ): Level crossing rate**, $F(\Gamma)$: Probability (CDF) for fading threshold Γ, $\pi_{g/b}$: Mean probability for good/bad state

Duration Modelling: 2-state Markov Chain

- Formulas for level crossing rates for common channel models available (see paper)
- Also for combination of small-/large-scale fading, pathloss and multi-antenna model
- It is an estimation, not a precise solution
  - **Conservative estimation?**
  - **Large deviation or within same magnitude?**
- Simulate wireless channel
  - MATLAB Communication Systems Toolbox
  - Compare to two-state Markov model sojourn time



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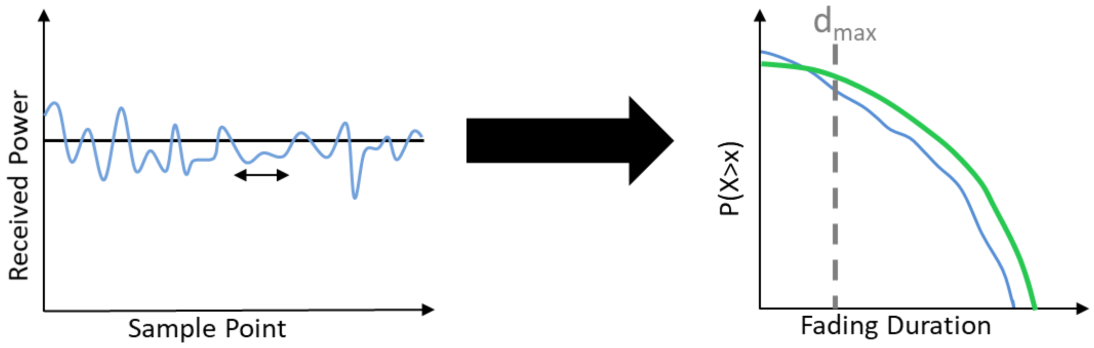

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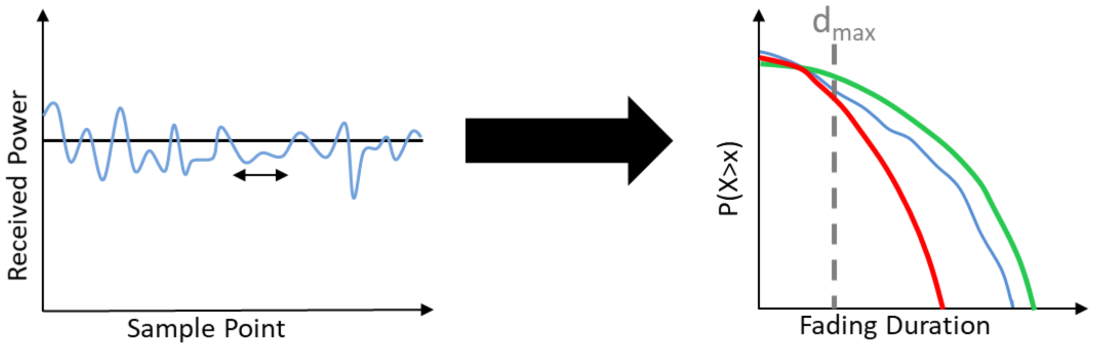

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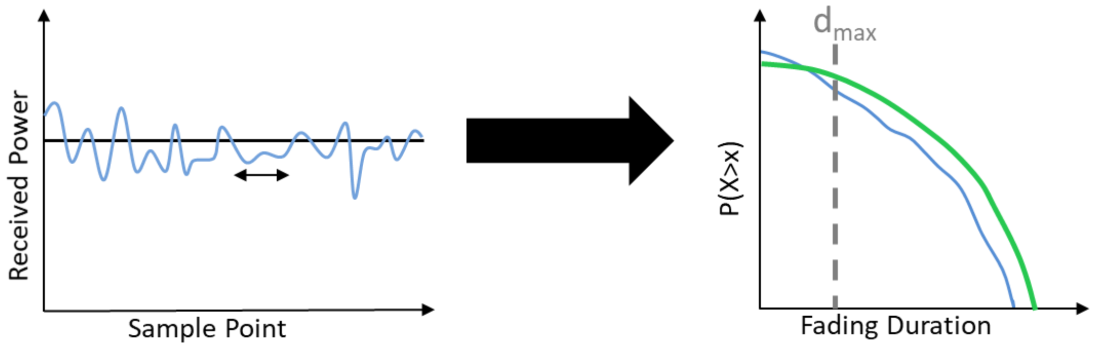


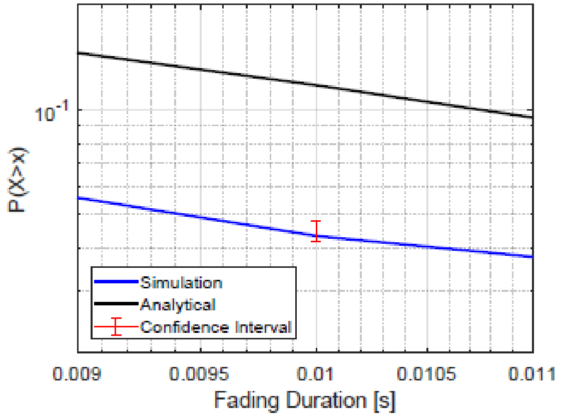
Model & Results

- Correlated, log-normal shadow fading
- Correlated, Nakagami-m small-scale fading (envelope)
- Combination of both through log-normal estimation

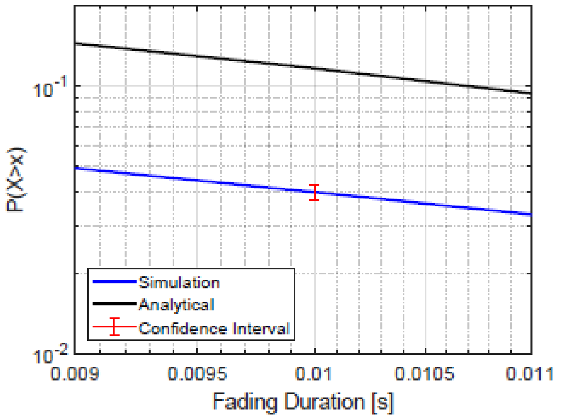
$$f(\gamma) = \int_0^\infty \underbrace{(\frac{m}{\Omega})^m \cdot \frac{\gamma^{m-1}}{\Gamma(m)} \cdot \exp(-m\frac{\gamma}{\Omega})}_{\text{Nakagami-}m\text{ fading PDF}} \cdot \underbrace{\frac{10}{log(10)\sqrt{2\pi}\sigma\Omega} \cdot \exp(-\frac{10log(\Omega-\mu)^2}{log(10)2\sigma^2})}_{\text{Log-normal fading PDF}} \; d\Omega$$

$$N(\gamma) = f_d \cdot \frac{20}{\sqrt{m} \cdot \Gamma(m) \cdot \pi \cdot log(10) \cdot \sqrt{2 \cdot log(2)}} \cdot (\frac{m}{\Omega})^m \cdot \int_0^\infty \frac{1}{y^2} \cdot (\frac{\gamma}{y})^{2m-1} \cdot \sqrt{m \cdot 2 \cdot \pi \cdot \sqrt{2 \cdot log(2)} \cdot (\frac{log(10) \cdot \sqrt{2 \cdot log(2)}}{20})^2 \cdot \gamma^2 + (2 \cdot \pi \cdot f_d \cdot y)^2} \cdot \exp(-\frac{m}{\Omega} \cdot (\frac{\gamma}{y})^2) \cdot \exp(-0.5 \cdot (20 \cdot \frac{log(y) - log(10) \cdot log_{10}(\Omega)}{log(10) \cdot \sqrt{2 \cdot log(2)}})^2) dy$$

Model & Results



Combined fading $\Gamma = -3\text{dB}$



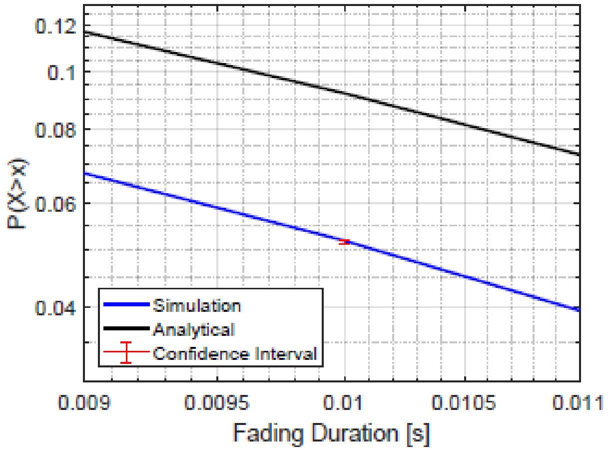
Combined fading $\Gamma = 0\text{dB}$

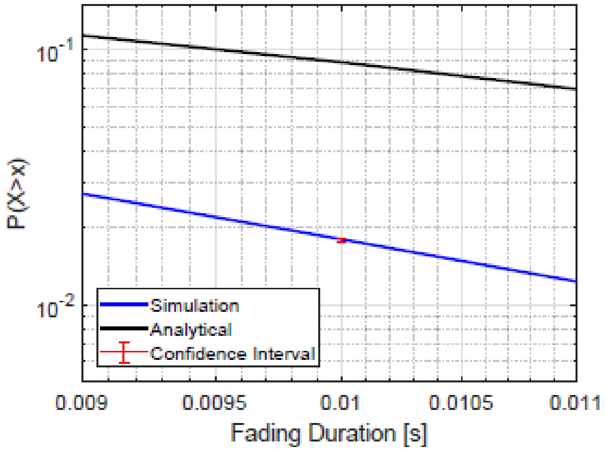
- Two different SINR thresholds Γ = -3 dB and Γ = 0 dB
- Other parameters motivated by various literature sources on channel modelling (see paper)
- 100 ms fading duration threshold

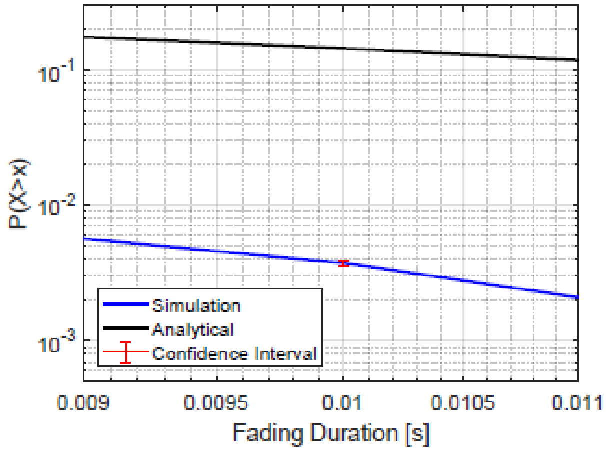
Probability for fading longer than 100 ms: ~10% from simulation vs. ~5% from model

- Simulation and analytical result from two-state Markov model are within same magnitude
- Model approximation is conservative

Model & Results







$K = -10dB$ $K = 3dB$ $K = 10dB$

- Two different Rician K-factors
- Other parameters motivated by various literature sources on channel modelling (see paper)
- 100 ms fading duration threshold

- Simulation and analytical result from two-state Markov model are within same magnitude
- Model approximation is conservative

Summary & Conclusion

Two state Markov model:

- Allows to analytically determine state sojourn time of `bad' state

Example: Considered path loss, shadow fading and small scale fading

- Approximate complex model to simple log-normal model
- Showed that approximation is "conservative"

Estimate parameters for practical use in protocol