Measurement-based Analysis of UMTS Link Characteristics

Advanced Wireless Communications 1 VU 389.168
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(http://www.nt.tuwien.ac.at/teaching/courses/winter-term/389168)
Repetition of the last lecture

- Fill out the missing bits ;)

![Diagram showing Super Frame, Timeslot, and Timeslot with intervals](image)
Repetition of the last lecture

- Fill out the missing bits ;}

![Diagram of Advanced Wireless Communications Layers][1]
Repetition of the last lecture

• Fill out the missing bits ;)

![Diagram showing the network structure with GGSN, SSGN, RNC, NodeB, IP Router, and NodeB]
Outline of this lecture

• Today: Errors on the link layer of UMTS!

• Ingredients
  - UMTS Network
  - UMTS Phone
  - DCH channel
  - TTI
  - TB

• Result:
  - Measured link error statistics
  - Input trace for modeling the link layer

TB  Transport Block
TTI  Transmission Time Interval
DCH  Dedicated Channel
Repetition: UMTS Network
Repetition: Packetization in UMTS

- Dedicated channel for every transmission
  - We need packetization for
    - Error control
    - Synchronization
    - Start/End of Transmission

- UMTS R99 packetization example
Repetition: IP Based Services

- Service data transmission over IP
  - UDP
    - Packet oriented data transmission
    - Lost packets are not retransmitted (at UDP layer)
    - Services: Real-time, Streaming, ...
  - TCP
    - Connection oriented data transmission
    - No data is lost in the TCP layer (retransmission)
    - Services: File transmission, eMail, ...

![Diagram showing the layers of the network stack with UDP and TCP at the transport layer, and application services like streaming and eMail at the top.]
Data transmission over IP

- Data transmission over IP as a function of
  - Transport protocol (TCP, UDP, RTP, ...)
  - Routing protocol
  - Physical Layer
    - Technology (GPRS, UMTS)
    - Link layer errors patterns
- Link layer and TCP/UDP interact via packet loss
  - Link layer statistic depends on the type of link
  - Mobile communication: Burst errors!
  - Land line based communication: Congestion
- Congestion
  - Stable (quite) probability a packet is dropped
- Burst error
  - Bunch of packets is lost
Data transmission over IP - Link layer

- Optimize higher layer services
  - Link layer statistics

- Next steps: Link Layer
  - Measuring the link layer (UMTS)
  - Analyzing the link layer
  - Modeling errors on the link layer (DCH)

- Typical procedure to model a system
  - Measurement of available parameters
  - Statistical analysis (CDF, PDF, ...)
  - Model/Parameter definition
  - Fitting of model parameters
Basics on Data Measurements
Recording of Data

- Any Ground-truth is unknown!
- When to trust your measurements?
  - Never ...

Preparation
- Select a parameter
- Define a recording process
- Define valid range
  - e.g. Datarate < Max(Technology) = 384kbit/s

Extraction
- Extract this feature
- Verify the result
  - Active/passive
  - Can we explain the differences?

Post-Processing
- Filter for outliers
- Manipulation?
- Next parameter
• Many statistical methods assume a stable generation process
  – Cannot be proven on a limited trace
  – Can be rejected for a trace

• Methods
  • Correlation analysis
    • Recorded data points independent
  • Moving average
    • Indication that the mean is stable within the trace
  • Scaling test
    • Variance is reduced with increased sample size

Verification of Data
Repetition: PDF, CDF, cCDF, ...

- A CDF (Cumulative Distribution Function) is
  - $F_x(x) = P(X<x)$
  - Between 0 and 1
- A cCDF is
  - $1 - CDF$
  - often displayed in LogLog
- PDF, CDF, cCDF cannot be measured from a trace
  - Can only be estimated from measurements
  - Assumptions needed
- Fitting parameters to well known distributions
  - Allows to reduce model input parameters
  - Typically two parameters define the full PDF
  - Problem - how to fit and verify!

$$f(x) = \alpha \beta x^{\beta-1} e^{-\alpha x^\beta}$$
Whisker Plots: Just a matter of definition

IQR Inter Quartile Range
Quartile

Q1, Q2, Q3

-2.698σ -0.6745σ 0.6745σ 2.698σ

24.65% 50% 24.65%

68.27% 15.73% 15.73%
The Mean -or- One Value to Fit Them All

• Often, by the "mean value"
  - A synthetic indicator of "typical" behavior
  - Intuitively, the larger the sample size $N$ (= number of data points), the closer the sample mean is to the "true" mean

• Example: sample extracted from a exp-neg distribution
What does the percentile value mean?

- Percentile is the value $x$ below which a certain percent of the observation fall
  - The 98th percentile cuts off the top 2% of the peaks
  - Robust against outliers
Beware of Magnitudes (Flow Level Analysis: Tail)

- A heavy-tail is...
  \[ P[X > x] \sim cx^{-\alpha}, \text{ as } x \to \infty, 0 < \alpha < 2 \]
  - Tail converges slowly,
  - Queuing does not work,
  - Traces are not heavy-tailed.

- Analysis method
  - Hill estimator
  - Scaling method

- Heavy-tailed flows
  - HTTP
  - TCP

\[ E(X) = \int_{-\infty}^{\infty} xf(x) \, dx \]
\[ \alpha = 1.09 \]
Summary: Measuring Data

- Verify recorded data based on system limits
- Verify recorded data based on statistical methods

- Derived parameters
  - The mean is just a number and a eCDF just a curve
  - Never process data unchecked

- Common source of problems
  - Not enough samples
  - Missing/Wrong filtering
  - Bi-modal distribution
  - Heavy tails

- More details on heavy-tails in the next lecture
Back to Topic ;}
• Perfect radio conditions
• Adjustable network parameters
• Reproducible results (?)

RNC: Radio Network Controller
SGSN: Serving GPRS Support Node
GGSN: Gateway GPRS Support Node
- TEMS mobiles
- Scenarios: static, non-static
- Service
  - UDP, downlink
  - 64, 128, 384kbit/s

RNC  Radio Network Controller
SGSN Serving GPRS Support Node
GGSN Gateway GPRS Support Node
Link Layer Statistics: Network Configurations

- Function of the bearer speed
- Parameters
  - Spreading Factor (SF)
    - 8, 16, 32, 64 ...
  - Transport Block (TB) size
    - Payload, RLC header
    - Atomic data entity
  - Transmission Time Interval (TTI) configuration
    - 10, 20, 40, 80ms

- Tested configuration
  - 384, 128, 64kbit/s

- Defined scenarios
  - Static
  - Small-scale movements
  - Walking
  - Tramway
  - Car

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**384kbit/s bearer:**

10ms = 1 TTI = 12 TBs, 336 bits per TB, SF 8

**128kbit/s bearer:**

20ms = 1 TTI = 8 TBs, 336 bits per TB, SF 16

**64kbit/s bearer:**

20ms = 1 TTI = 4 TBs, 336 bits per TB, SF 32
### Link Layer Statistics: Link Error Analysis

<table>
<thead>
<tr>
<th>Scenario</th>
<th>$P_e$(TB)</th>
<th>$P_e$(TTI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static</td>
<td>0.266%</td>
<td>0.472%</td>
</tr>
<tr>
<td>Small-scale</td>
<td>2.2%</td>
<td>2.34%</td>
</tr>
<tr>
<td>Large-scale</td>
<td>2.03%</td>
<td>2.63%</td>
</tr>
</tbody>
</table>

- **TB error probability**
  - Two scenarios: static, movement

- **Static**
  - OLPC does not meet set error target of 1%

- **Small-scale**
  - Power control cannot adjust to multipath propagation

- Considering a BSC $P_e$(TTI) should be around 15%!
Modeling Erroneous Channels
The Binary Symmetric Channel (BSC)

- Introduced by Shannon in 1948
- Simple channel for transmission of information
- Allows to transmit single bits
- Errors change $0 \rightarrow 1$ or vice versa
- Memory-less channel
  - Error events are independent
  - $P_e$ for a given number of bits $x$ can be calculated from $1-(1-p)^x$
The Binary Erasure Channel (BEC)

- Introduced by Elias in 1954
- Error state instead of bit flipping
- Memory-less channel
- Equivalent to an error source model
- No burst errors
The Gilbert Model

- Introduced in 1960 by Gilbert
- Two state model:
  - Good/Bad: no errors/ errors
- First order two state Markov model (more next time)
- Burst/gap length are independent from each other!

**Gilbert-Elliot**

\[
\begin{align*}
\text{P}(1|G) &= 0 \\
0 < \text{P}(1|B) &\leq 1
\end{align*}
\]
Error Models

- **BSC**
  - Bit inversion only

- **BEC**
  - Error indicator

- **Gilbert (Elliot)**
  - No Error / Error state

- **Memory less models**
  - Simple definition
  - Cannot reproduce correlation between error events

- **Model with memory state**
  - Parameter extraction from a trace is not unique
Back to Topic ;)
All Scenarios: Erroneous TBs/TTI

- Number of erroneous TBs in TTIs
  - Movement / Fading: all TBs lost in a TTI
  - No Movement / Reference scenario: shows only one lost TB/TTI
  - Introduce TTI-gap- and burstlength
Definition: TTI burst-/gaplength

- **TTI-gaplength:** is the number of subsequently received error-free TTIs.
- **TTI-burstlength:** is the number of subsequent erroneous TTIs.
- **Error cluster:** a group of erroneously received TTIs separated by at most $L_c$ error-free TTIs (ITU !)
Mobile Scenario: TTI burst-/gaplength

- Non static
  - Error-free length of up to 700 TTIs
  - Error bursts up to 20 TTIs
Static Scenario: TB burst-/gaplength

- Static scenario
  - TB burst-/gaplength instead of TTI
  - Long and short gaplength
  - Static 3 = reference network = no impacts from radio!

![Graph showing empirical CDF for gaplength and burstlength with three static scenarios: static 1, static 2, and static 3.](image)
Link Layer Statistics: Power Control

- CDMA needs power control
  - UMTS: ILPC (fast changes) and OLPC (slow changes)
  - OLPC not defined in the standard
  - Algorithm might introduce correlation between errors
Correlation between Gap/Burst Correlations

- OLPC introduces correlation between gaps and bursts
  - If we now about the current state we can predict error free future
  - Gilbert-Elliot model cannot model such behavior
UMTS Link Layer Analysis

- Two scenarios
  - Static
  - Non-static

- BSC channel cannot model TB errors
  - Error bursts and gaps

- Non-static
  - Fading results in loss of all TBs/TTI
  - Small movement results in same error patterns as large scale movement

- Static
  - OLPC introduces correlation between error burst and gap
Summary of this lecture

• Measurement of real world data
  - Meaning of the “mean”

• Measuring errors on UMTS link layer
  - Record TB and TTI statistics
  - Analyze for different scenarios
  - Scenarios: static, non-static
  - All non-static are similar

• Burstiness of errors
  - Proper error model has to be chosen

• Correlation of the error pattern due to the OLPC
  - Lower layer signaling interferes with data plane!
Next time

• Modeling erroneous channels
  - BSC
  - Hidden Markov Model (HMM)

• Error prediction for a DCH channel
  - IP level
  - Video streaming
Thank you for your attention

Questions?
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Static Scenario: Clustering TB errors

- Analyze the error clusters
  - Minimum gap set to 12
  - Maximum of 24 TBs combined to a cluster