# Wireless Networking [ET4394]

## Edition 2018: Wireshark, NS3 and SDR

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# Learning Objectives

- **LO1**: Crash Course on Wireshark
- **LO2:** Crash Course on NS3
- **LO3:** Crash Course on SDR

# Part 1: Wireshark

# Wireshark

- **No need to say more:**
  - (almost) all groups are working hard on the assignments
  - Thank you! Thank you! Thank you!
- **Documentation**
  - https://www.wireshark.org/docs/
  - Links provided in next slides
- **Want to be up to date?**
  - https://www.wireshark.org/about-sharkfest.html

# Wireshark: Comments on Report

- **Write your own software**
  - Running someone else’s code is not good
  - **Cite explicitly what you re-use**
- **I expect some science in your Wireshark experiments**
  - See examples later on
- **There are tons of papers on WiFi measurements**
  - Google first (examples later on)
  - Cite in your report
  - Compare results (see examples later on)

# Wireshark: Example “Sniffs”

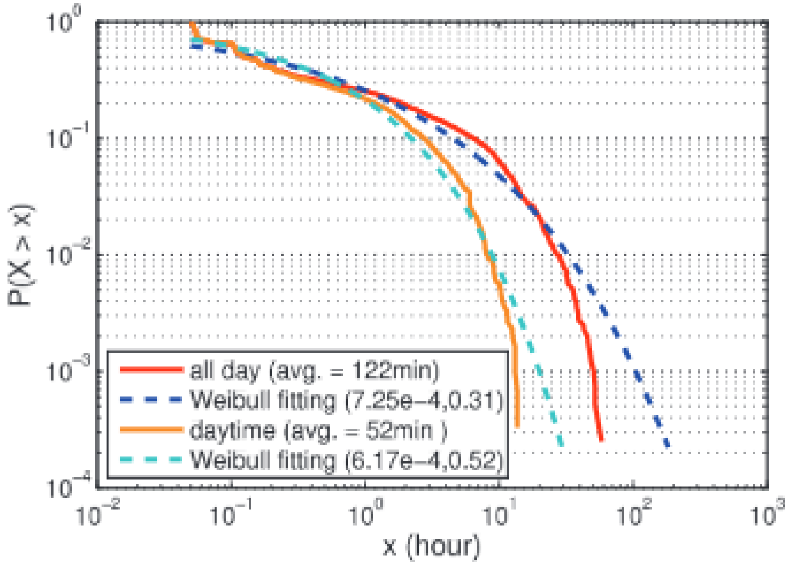


**Figure 5: The CCDF of connection duration. The average connection duration is 122 minutes. The distribution fits well with a Weibull distribution with $k = 0.31$ for all day and $k = 0.52$ for daytime. $\alpha$ parameter is also given in the bracket.**

Lee et al. **Mobile Data Offoading: How Much Can WiFi Deliver?**
ACM CoNEXT, Nov. 30 - Dec. 3, 2010, Philadelphia, PA, USA
http://netsys.kaist.ac.kr/publication/papers/Resources/[IJ107].pdf

# Wireshark: Example “Sniffs”

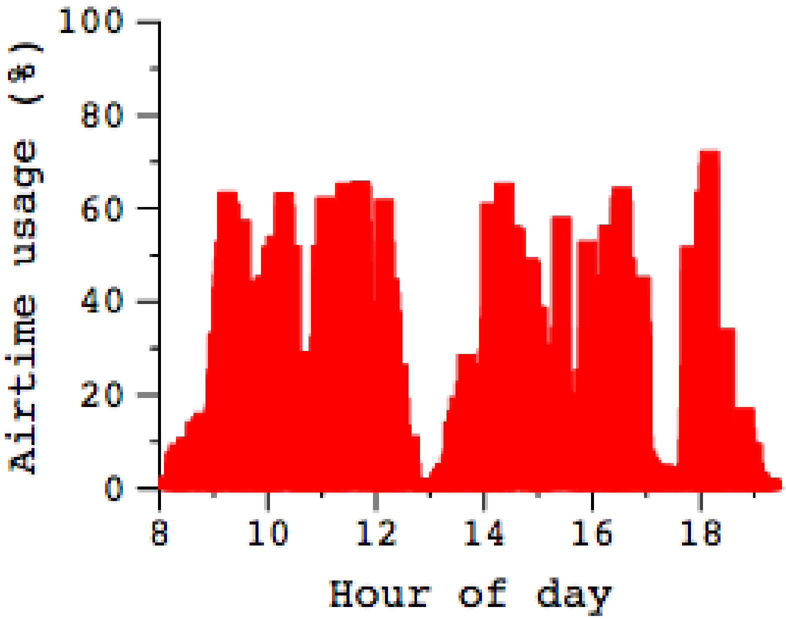
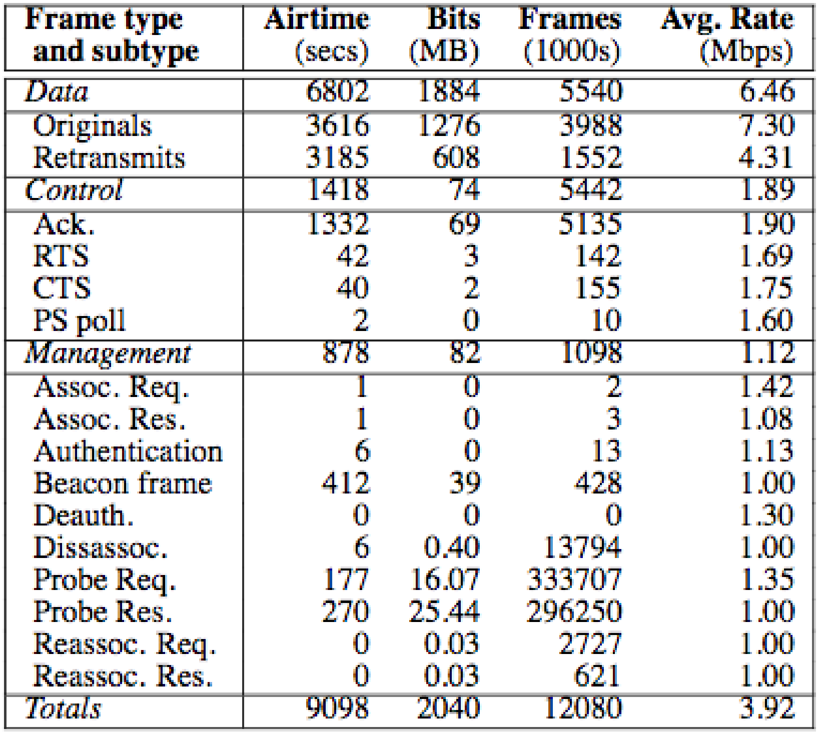


**Figure 2: Airtime utilization over time. The binning interval is one minute.**

Rodrig et al. **Measurement-based Characterization of 802.11 in a Hotspot Setting**, ACM SIGCOMM’05 Workshop, Aug. 22–26, 2005, Philadelphia, PA, USA
http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.80.6621&rep=rep1&type=pdf

# Wireshark: Example “Sniffs”

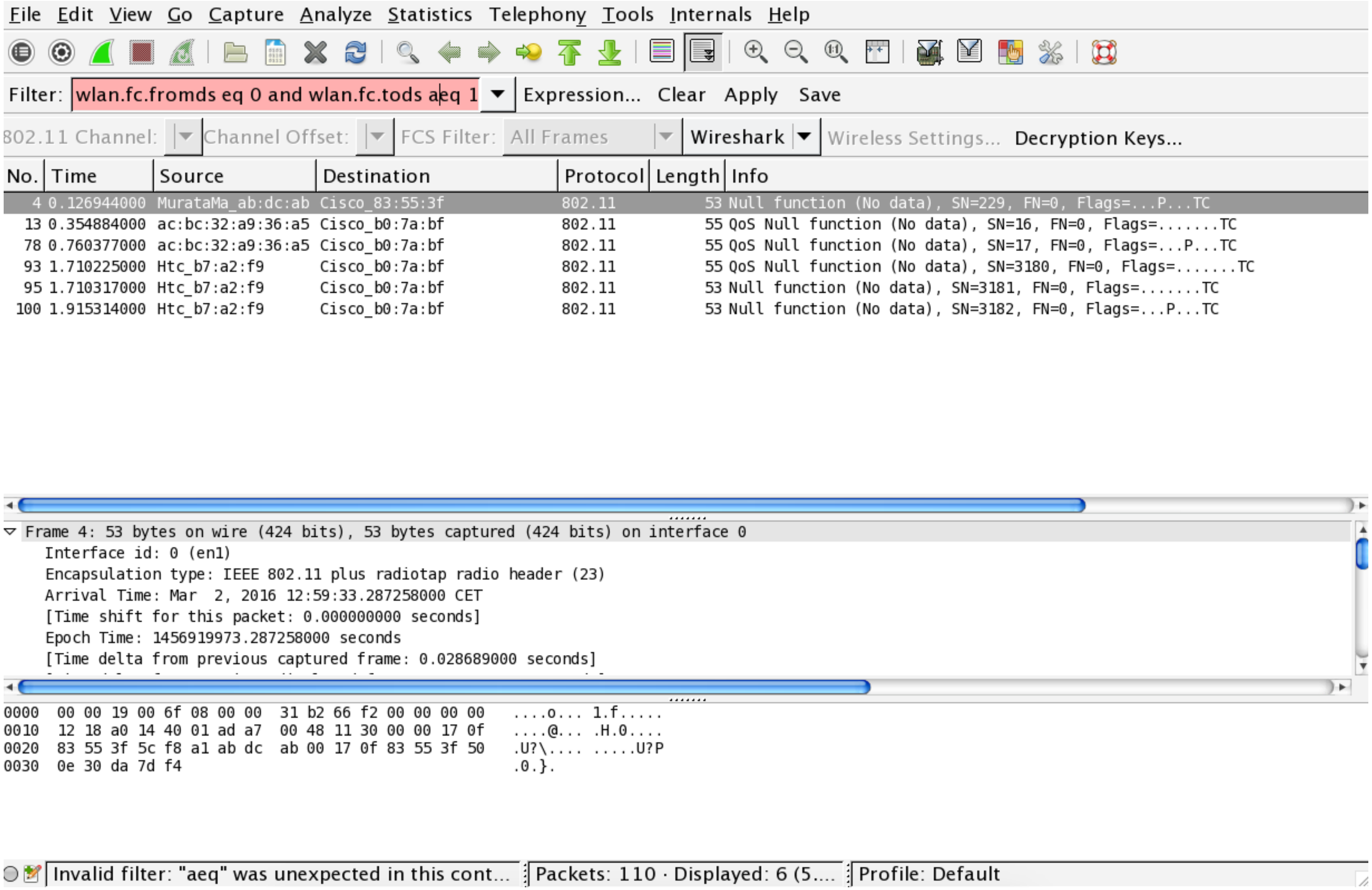


| Frame type and subtype | Airtime (secs) | Bits (MB) | Frames (1000s) | Avg. Rate (Mbps) |
|---|---|---|---|---|
| *Data* | 6802 | 1884 | 5540 | 6.46 |
| Originals | 3616 | 1276 | 3988 | 7.30 |
| Retransmits | 3185 | 608 | 1552 | 4.31 |
| *Control* | 1418 | 74 | 5442 | 1.89 |
| Ack. | 1332 | 69 | 5135 | 1.90 |
| RTS | 42 | 3 | 142 | 1.69 |
| CTS | 40 | 2 | 155 | 1.75 |
| PS poll | 2 | 0 | 10 | 1.60 |
| *Management* | 878 | 82 | 1098 | 1.12 |
| Assoc. Req. | 1 | 0 | 2 | 1.42 |
| Assoc. Res. | 1 | 0 | 3 | 1.08 |
| Authentication | 6 | 0 | 13 | 1.13 |
| Beacon frame | 412 | 39 | 428 | 1.00 |
| Deauth. | 0 | 0 | 0 | 1.30 |
| Dissassoc. | 6 | 0.40 | 13794 | 1.00 |
| Probe Req. | 177 | 16.07 | 333707 | 1.35 |
| Probe Res. | 270 | 25.44 | 296250 | 1.00 |
| Reassoc. Req. | 0 | 0.03 | 2727 | 1.00 |
| Reassoc. Res. | 0 | 0.03 | 621 | 1.00 |
| *Totals* | 9098 | 2040 | 12080 | 3.92 |

**Table 2: Breakdown by frame type and subtype. (Originals and Retransmits are not 802.11 frame subtypes; we list them here for ease of exposition.)**

Rodrig et al. **Measurement-based Characterization of 802.11 in a Hotspot Setting**, ACM SIGCOMM’05 Workshop, Aug. 22–26, 2005, Philadelphia, PA, USA
http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.80.6621&rep=rep1&type=pdf

# Wireshark: GUI


File Edit View Go Capture Analyze Statistics Telephony Tools Internals Help
Expression... Clear Apply Save
802.11 Channel:
Channel Offset:
FCS Filter: All Frames
Wireshark
Wireless Settings... Decryption Keys...

Filter: wlan.fc.fromds eq 0 and wlan.fc.tods aeq 1

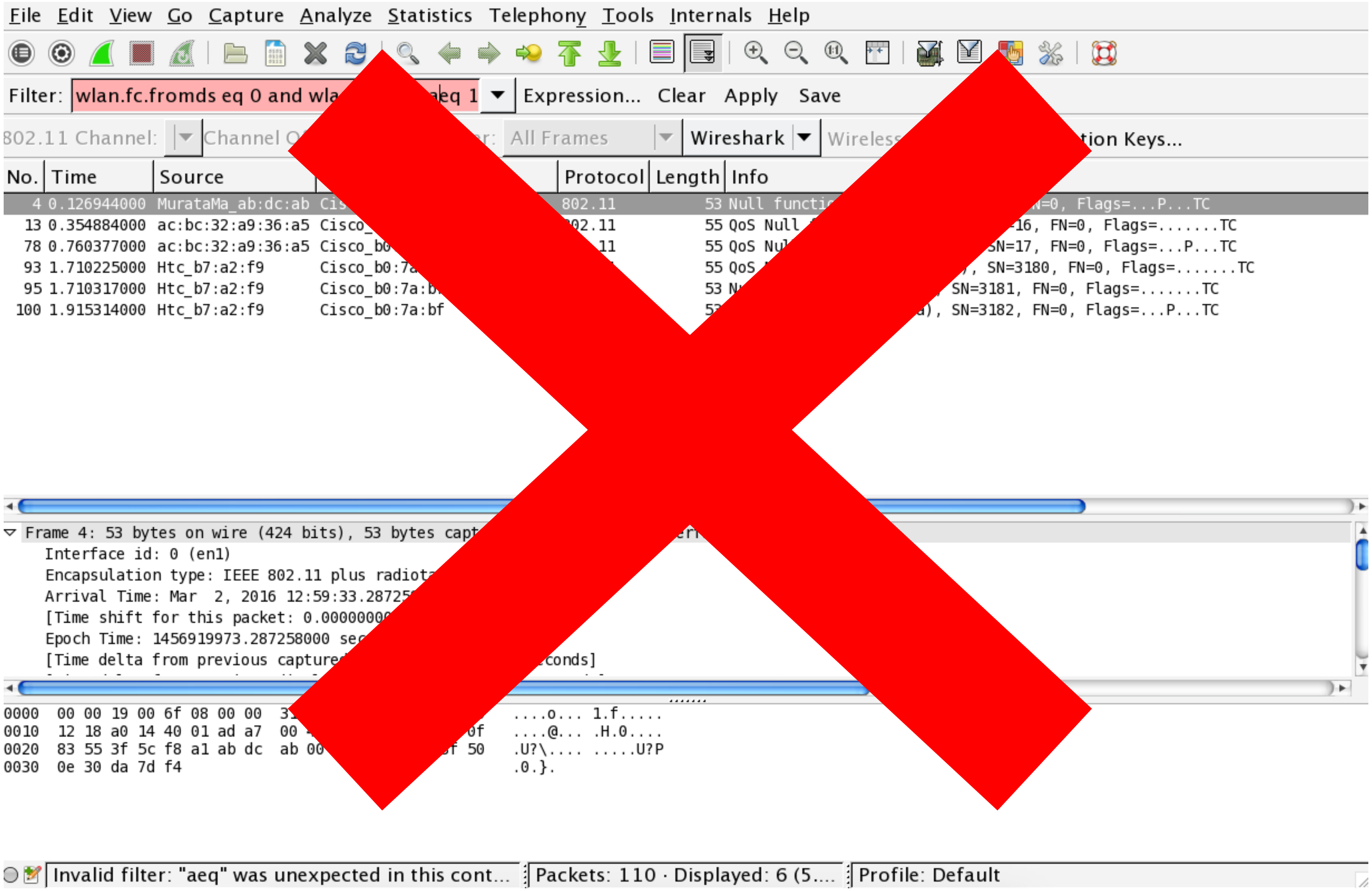
```
No. Time        Source            Destination     Protocol Length Info
  4 0.126944000 MurataMa_ab:dc:ab Cisco_83:55:3f  802.11       53 Null function (No data), SN=229, FN=0, Flags=...P...TC
 13 0.354884000 ac:bc:32:a9:36:a5 Cisco_b0:7a:bf  802.11       55 QoS Null function (No data), SN=16, FN=0, Flags=.......TC
 78 0.760377000 ac:bc:32:a9:36:a5 Cisco_b0:7a:bf  802.11       55 QoS Null function (No data), SN=17, FN=0, Flags=...P...TC
 93 1.710225000 Htc_b7:a2:f9      Cisco_b0:7a:bf  802.11       55 QoS Null function (No data), SN=3180, FN=0, Flags=.......TC
 95 1.710317000 Htc_b7:a2:f9      Cisco_b0:7a:bf  802.11       53 Null function (No data), SN=3181, FN=0, Flags=.......TC
100 1.915314000 Htc_b7:a2:f9      Cisco_b0:7a:bf  802.11       53 Null function (No data), SN=3182, FN=0, Flags=...P...TC
```

```
▽ Frame 4: 53 bytes on wire (424 bits), 53 bytes captured (424 bits) on interface 0
    Interface id: 0 (en1)
    Encapsulation type: IEEE 802.11 plus radiotap radio header (23)
    Arrival Time: Mar  2, 2016 12:59:33.287258000 CET
    [Time shift for this packet: 0.000000000 seconds]
    Epoch Time: 1456919973.287258000 seconds
    [Time delta from previous captured frame: 0.028689000 seconds]
```

```
0000  00 00 19 00 6f 08 00 00  31 b2 66 f2 00 00 00 00   ....o... 1.f.....
0010  12 18 a0 14 40 01 ad a7  00 48 11 30 00 00 17 0f   ....@... .H.0....
0020  83 55 3f 5c f8 a1 ab dc  ab 00 17 0f 83 55 3f 50   .U?\.... .....U?P
0030  0e 30 da 7d f4                                     .0.}.
```

Invalid filter: "aeq" was unexpected in this cont... | Packets: 110 · Displayed: 6 (5.... | Profile: Default

# Wireshark: GUI


File Edit View Go Capture Analyze Statistics Telephony Tools Internals Help
Expression... Clear Apply Save
802.11 Channel:
Channel O
All Frames
Wireshark
Wireless
tion Keys...

Filter: wlan.fc.fromds eq 0 and wla aeq 1

```
No. Time        Source            Cis                           Protocol Length Info
  4 0.126944000 MurataMa_ab:dc:ab Cis                           802.11       53 Null functi               N=0, Flags=...P...TC
 13 0.354884000 ac:bc:32:a9:36:a5 Cisco_                        02.11        55 QoS Null               16, FN=0, Flags=.......TC
 78 0.760377000 ac:bc:32:a9:36:a5 Cisco_b0                        11         55 QoS Nul               SN=17, FN=0, Flags=...P...TC
 93 1.710225000 Htc_b7:a2:f9      Cisco_b0:7a                                55 QoS                 ), SN=3180, FN=0, Flags=.......TC
 95 1.710317000 Htc_b7:a2:f9      Cisco_b0:7a:b                              53 N                 , SN=3181, FN=0, Flags=.......TC
100 1.915314000 Htc_b7:a2:f9      Cisco_b0:7a:bf                             53                 a), SN=3182, FN=0, Flags=...P...TC
```

```
▽ Frame 4: 53 bytes on wire (424 bits), 53 bytes capt                  er
    Interface id: 0 (en1)
    Encapsulation type: IEEE 802.11 plus radiota
    Arrival Time: Mar  2, 2016 12:59:33.28725
    [Time shift for this packet: 0.00000000
    Epoch Time: 1456919973.287258000 sec
    [Time delta from previous capture                   conds]
```

```
0000  00 00 19 00 6f 08 00 00  31                 ....o... 1.f.....
0010  12 18 a0 14 40 01 ad a7  00               0f ....@... .H.0....
0020  83 55 3f 5c f8 a1 ab dc  ab 00            f 50 .U?\.... .....U?P
0030  0e 30 da 7d f4                              .0.}.
```

Invalid filter: "aeq" was unexpected in this cont... | Packets: 110 · Displayed: 6 (5.... | Profile: Default

# Wireshark: Filters

- You already know that the data flowing through the WLAN interface is massive
    - So we need to filter it

# Wireshark: Frame Detail

- **Arrival Time:** frame.time
- **Time delta from previous packet:** frame.time_delta
- **Time since reference or first frame:** frame.time_relative
- **Frame number:** frame.number
- **Packet Length:** frame.pkt_len
- **Capture length:** frame.cap_len
- **Protocols in frame:** frame.protocols
  - i.e. All protocols that are encapsulated (starting from 802.11 header)

- **More:** "Wireless Sniffing with Wireshark"

  (http://www.willhackforsushi.com/books/377_eth_2e_06.pdf)

# Wireshark: 802.11 Header Fields

- **Frame control:** wlan.fc
  - **Type/Subtype:** wlan.fc.type_subtype
    - Not represented by 802.11 header: form of Wireshark convenience
  - **Version:** wlan.fc.version
  - **Subtype:** wlan.fc.subtype
  - **Flags:** wlan.fc.flags
  - **Distribution System status:** wlan.fc.ds
    - Which direction: AP→STA or STA→AP?
  - **More fragments:** wlan.fc.flag
  - **Retry:** wlan.fc.retry
  - **Power management:** wlan.fc.pwrmgmt
  - **More data:** wlan.fc.moredata
- **More:** "Wireless Sniffing with Wireshark" (http://www.willhackforsushi.com/books/377_eth_2e_06.pdf)

# Wireshark: 802.11 Header Fields

- **Protected:** wlan.fc.protected
    - Data encrypted or not?
- **Order:** wlan.fc.order
    - Must frames be handled in strict order?
- **Duration:** wlan.duration
- **Address fields:** wlan.da, wlan.sa, wlan.bssid, wlan.ra
- **Fragment number:** wlan.frag
- **Sequence number:** wlan.seq

- **More:** "Wireless Sniffing with Wireshark"

  (http://www.willhackforsushi.com/books/377_eth_2e_06.pdf)

# Wireshark: Comparison Operators

- eq == (ip.src==10.0.0.5)
- ne != (ip.src!=10.0.0.5)
- gt > (frame.len > 10)
- lt < (frame.len < 128)
- ge >= (frame.len ge 0x100)
- le <= (frame.len <= 0x20)

- **More:** https://www.wireshark.org/docs/wsug_html_chunked/ChWorkBuildDisplayFilterSection.html

# Wireshark: Logical Operators

- and && (ip.src==10.0.0.5 and tcp.flags.fin)
- or || (ip.scr==10.0.0.5 or ip.src==192.1.1.1)
- xor ^^ (tr.dst[0:3] == 0.6.29 xor tr.src[0:3] == 0.6.29)
- not ! (not llc)
- […]

- **More:** https://www.wireshark.org/docs/wsug_html_chunked/ChWorkBuildDisplayFilterSection.html

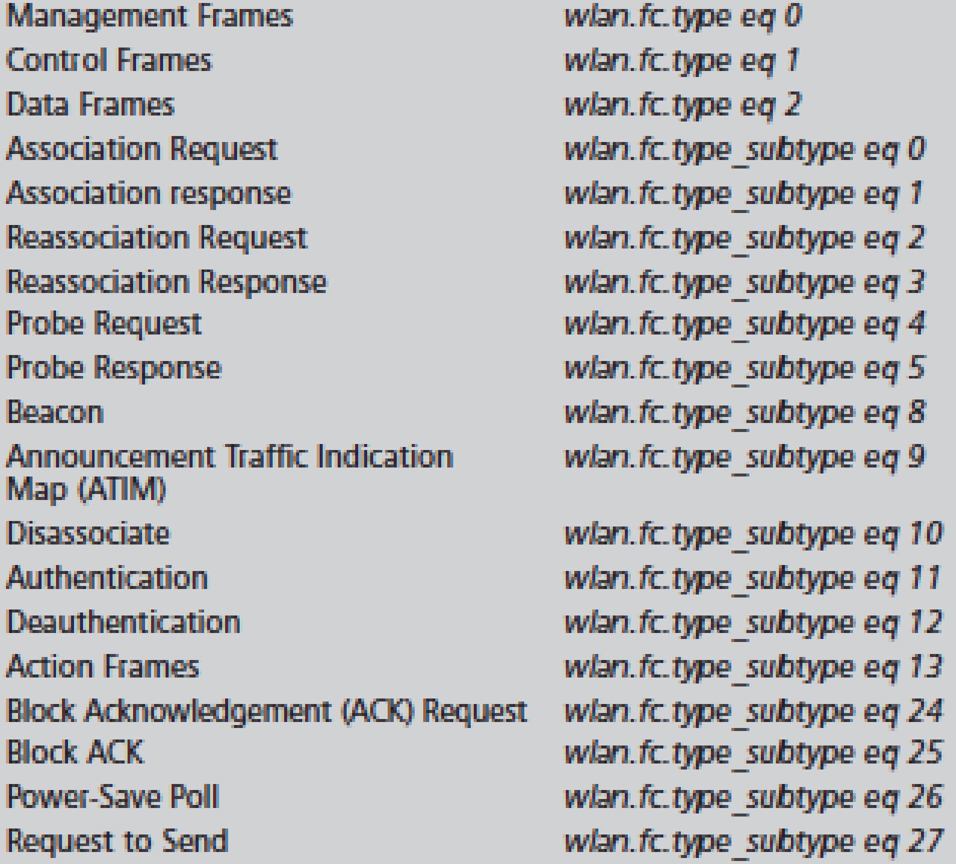
# Wireshark: Example filters

- **Filter for MAC address**
  - wlan.sa eq 00:09:5b:e8:c4:03
  - wlan.sa eq 00:09:5b:e8:c4:03 and wlan.bssid ne ff:ff:ff:ff:ff:ff
- **Filter for BSSID**
  - wlan.bssid eq 00:11:92:6e:cf:00
  - In GUI: Go to IEEE 802.11 Wireless LANManagement Frame | Tagged Parameters | SSID Parameter Set | TagInterpretation
    - wlan_mgt.tag.interpretation eq "NOWIRE"

- **More: More: "**Wireless Sniffing with Wireshark"

  (http://www.willhackforsushi.com/books/377_eth_2e_06.pdf)

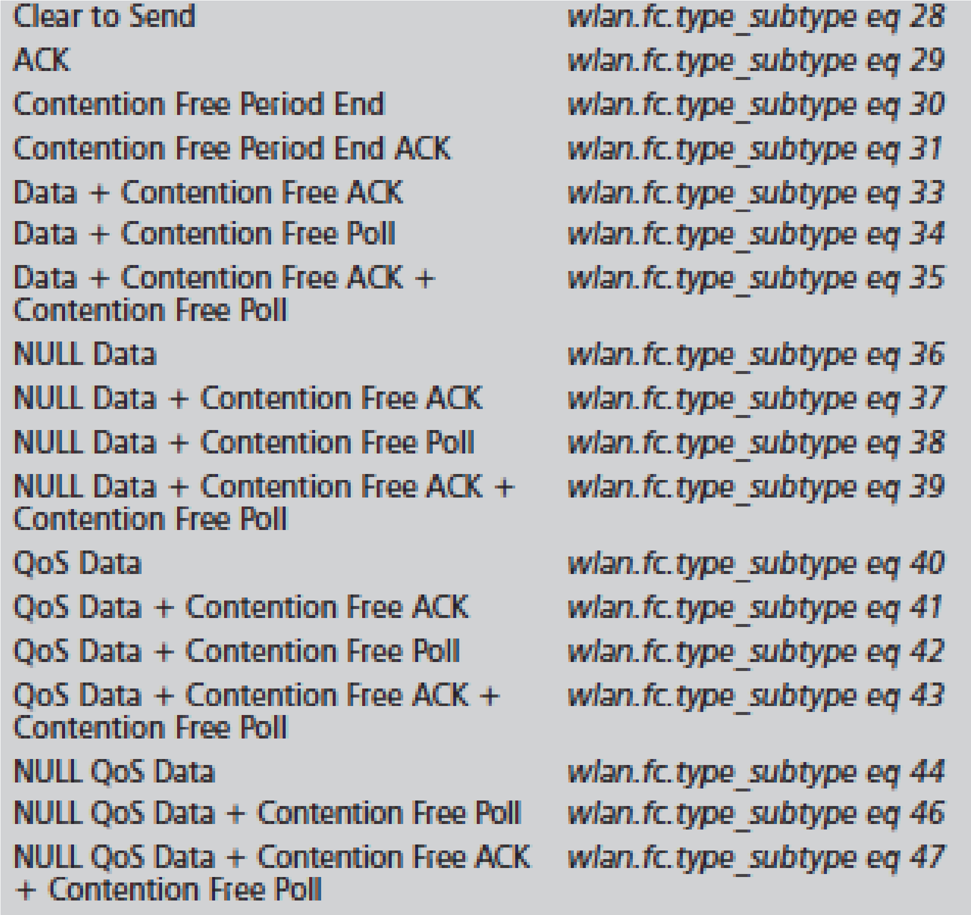
# Wireshark: Frame types



| | |
|---|---|
| Management Frames | *wlan.fc.type eq 0* |
| Control Frames | *wlan.fc.type eq 1* |
| Data Frames | *wlan.fc.type eq 2* |
| Association Request | *wlan.fc.type_subtype eq 0* |
| Association response | *wlan.fc.type_subtype eq 1* |
| Reassociation Request | *wlan.fc.type_subtype eq 2* |
| Reassociation Response | *wlan.fc.type_subtype eq 3* |
| Probe Request | *wlan.fc.type_subtype eq 4* |
| Probe Response | *wlan.fc.type_subtype eq 5* |
| Beacon | *wlan.fc.type_subtype eq 8* |
| Announcement Traffic Indication Map (ATIM) | *wlan.fc.type_subtype eq 9* |
| Disassociate | *wlan.fc.type_subtype eq 10* |
| Authentication | *wlan.fc.type_subtype eq 11* |
| Deauthentication | *wlan.fc.type_subtype eq 12* |
| Action Frames | *wlan.fc.type_subtype eq 13* |
| Block Acknowledgement (ACK) Request | *wlan.fc.type_subtype eq 24* |
| Block ACK | *wlan.fc.type_subtype eq 25* |
| Power-Save Poll | *wlan.fc.type_subtype eq 26* |
| Request to Send | *wlan.fc.type_subtype eq 27* |

- **More:** “Wireless Sniffing with Wireshark” (http://www.willhackforsushi.com/books/377_eth_2e_06.pdf)

# Wireshark: Frame types



| | |
|---|---|
| Clear to Send | *wlan.fc.type_subtype eq 28* |
| ACK | *wlan.fc.type_subtype eq 29* |
| Contention Free Period End | *wlan.fc.type_subtype eq 30* |
| Contention Free Period End ACK | *wlan.fc.type_subtype eq 31* |
| Data + Contention Free ACK | *wlan.fc.type_subtype eq 33* |
| Data + Contention Free Poll | *wlan.fc.type_subtype eq 34* |
| Data + Contention Free ACK + Contention Free Poll | *wlan.fc.type_subtype eq 35* |
| NULL Data | *wlan.fc.type_subtype eq 36* |
| NULL Data + Contention Free ACK | *wlan.fc.type_subtype eq 37* |
| NULL Data + Contention Free Poll | *wlan.fc.type_subtype eq 38* |
| NULL Data + Contention Free ACK + Contention Free Poll | *wlan.fc.type_subtype eq 39* |
| QoS Data | *wlan.fc.type_subtype eq 40* |
| QoS Data + Contention Free ACK | *wlan.fc.type_subtype eq 41* |
| QoS Data + Contention Free Poll | *wlan.fc.type_subtype eq 42* |
| QoS Data + Contention Free ACK + Contention Free Poll | *wlan.fc.type_subtype eq 43* |
| NULL QoS Data | *wlan.fc.type_subtype eq 44* |
| NULL QoS Data + Contention Free Poll | *wlan.fc.type_subtype eq 46* |
| NULL QoS Data + Contention Free ACK + Contention Free Poll | *wlan.fc.type_subtype eq 47* |

- **More:** “Wireless Sniffing with Wireshark” (http://www.willhackforsushi.com/books/377_eth_2e_06.pdf)

# Wireshark: Example filters

- **Beacon frame type/subtype**
  - !(wlan.fc.type eq 0 and wlan.fc.subtype eq 8)
  - wlan.fc.type eq 2 and !(wlan.fc.subtype eq 4)

- **More: "**Wireless Sniffing with Wireshark"

  (http://www.willhackforsushi.com/books/377_eth_2e_06.pdf)

# Wireshark: Example filters

- **Marking From DS and To DS**
  - wlan.fc.fromds eq 0 and wlan.fc.tods eq 1

- **More: "**Wireless Sniffing with Wireshark"

  (http://www.willhackforsushi.com/books/377_eth_2e_06.pdf)

# Wireshark: Your Voice!

**What is your experience so far?**

**Any suggestions and tips?**

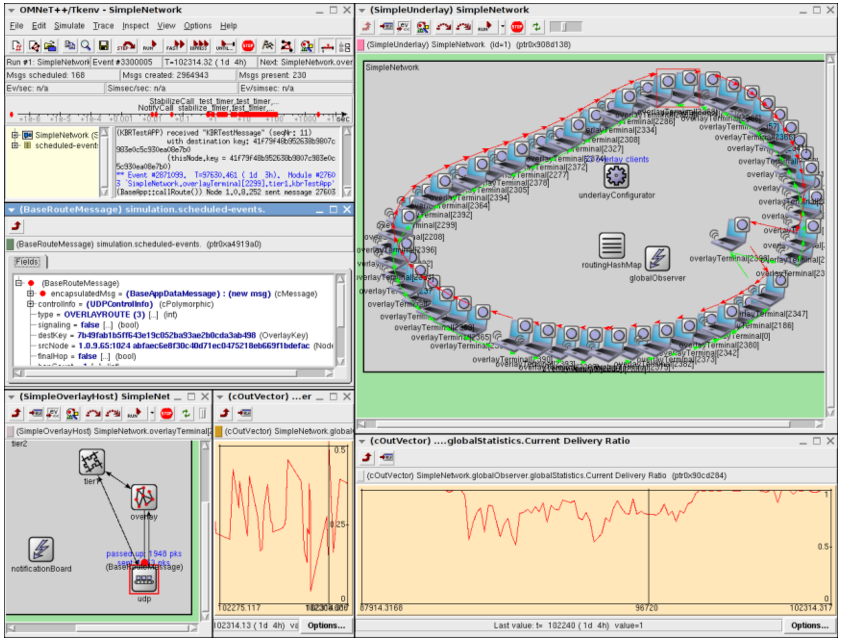
# Part 2: NS3

# Literature

- **Simulator overview**
  - E. Weingartner, H. vom Lehn, K. Wehrle, **A performance comparison of recent network simulators**, Proc. IEEE ICC 2009
    - http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5198657
  - D. Hiranandani, K. Obraczka, J.J. Garcia-Luna-Aceves, **MANET protocol simulations considered harmful: the case for benchmarking,** IEEE Wireless Communications, vol. 20, no. 4, pp. 82-90, Aug. 2013,
    - http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6590054

# Network simulation

A process of verifying/understanding/testing the performance of a (wireless) communication network, by means of replication of interaction between network entities in in a computer program



```
(KBRTestAPP) received "KBRTestMessage" (seqNr: 11)
              with destination key: 41f79f48b952638b9807c
983e0c5c930ea08e7b0
              (thisNode.key = 41f79f48b952638b9807c983e0c
5c930ea08e7b0)
** Event #2871099.  T=97630.461 ( 1d  3h).  Module #2760
3 `SimpleNetwork.overlayTerminal[2299].tier1.kbrTestApp'
(BaseApp::callRoute()) Node 1.0.8.252 sent message 27603
```

(BaseRouteMessage) simulation.scheduled-events. (ptr0xa4919a0)

```
(BaseRouteMessage)
  encapsulatedMsg = (BaseAppDataMessage) : (new msg) (cMessage)
  controlInfo = (UDPControlInfo) (cPolymorphic)
  type = OVERLAYROUTE (3) [...] (int)
  signaling = false [...] (bool)
  destKey = 7b49fab1b5ff643e19c052ba93ae2b0cda3ab498 (OverlayKey)
  srcNode = 1.0.9.65:1024 abfaec6e8f30c40d71ec0475218eb669f1bdefac (Node
  finalHop = false [...] (bool)
```

(SimpleUnderlay) SimpleNetwork (id=1) (ptr0x908d138)

(SimpleOverlayHost) SimpleNetwork.overlayTerminal[2

http://www.oversim.org/wiki/OverSimFeatures

# Purpose of Network Simulation

- **Alternatives**
  - Implementation: gnuradio.org/redmine/projects/gnuradio/wiki/USRP
  - Testbeds: www.planet-lab.org, www.onelab.eu ,www.emulab.net
- **Pros**
  - Ease of test setup
  - Fine control of network parameters
  - Replicable
- **Cons**
  - Not as good as
    - Building
    - Measuring
  - Difficult to manipulate (buggy)

Rutgers University, http://www.orbit-lab.org

# Network simulators on the market

- **Most popular custom-built**
  - http://www.**opnet**.com [OPNET]
  - http://www.**omnetpp**.org [OmNet++]
  - http://www.isi.edu/nsnam/ns/ [NS2]
  - http://www.nsnam.org [NS3]
  - **Less popular custom-built**
    - http://**tetcos**.com [NetSim]
    - http://web.scalable-networks.com/content/**qualnet** [Qualnet]
      - **Even less popular custom-built**
        - https://**simpy**.readthedocs.org/en/latest/ [Simpy]
        - http://**jist**.ece.cornell.edu [Jist]

# Types of Simulators

- **Continuous (real-time)**
  - Time-sliced
  - Runs through each state even if nothing happens
- **Process-based**
  - Process is a thread in simulation
  - Threads wake/sleep others
- **Discrete-based**
  - Per event: **Queue** and **Teller/Server**
  - Much faster

# Matlab/Octave: Overview

- **Website:** https://www.gnu.org/software/octave/ http://www.mathworks.nl/products/matlab/

- **Pros**
  - Easy to use
  - Quick and dirty
  - Familiar
- **Cons**
  - Too simplistic
  - Not accepted by (a highbrow) community

# Matlab/Octave: Example

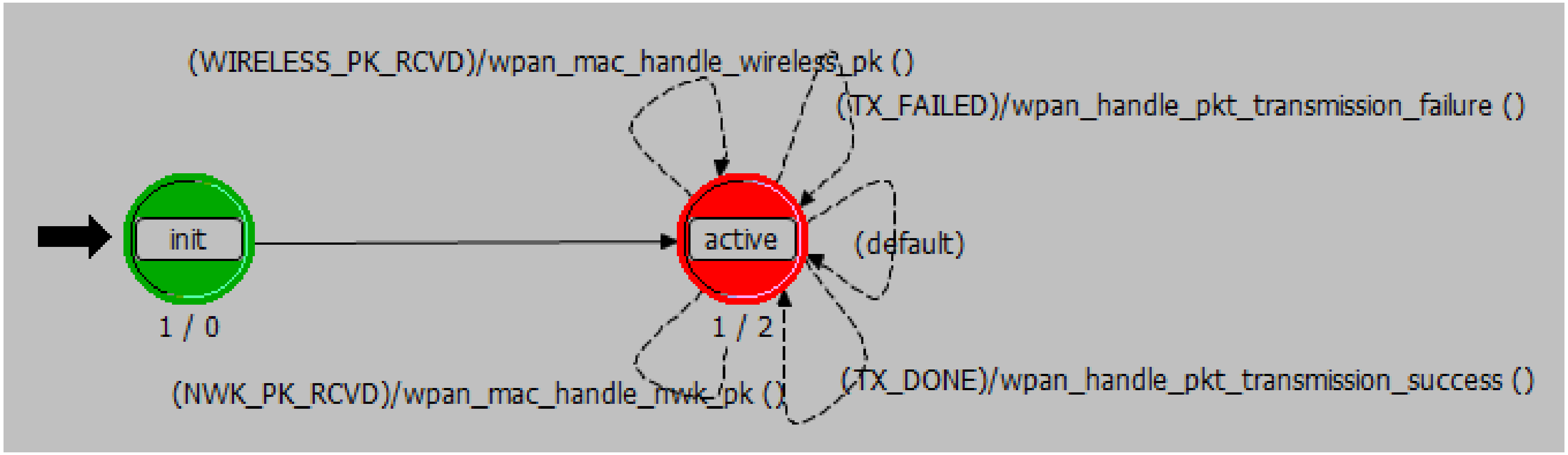
```
number_packets=10000;
error_probability=1e-5;
transmitted_packet=[];
For k=1:number_packets
   correct_packet=rand>1-error_probability;
   transmitted_packet=[correct_packet,transmitted_packet];
End
mean_error=mean(transmitted_packets);
```

# OPNET: Overview

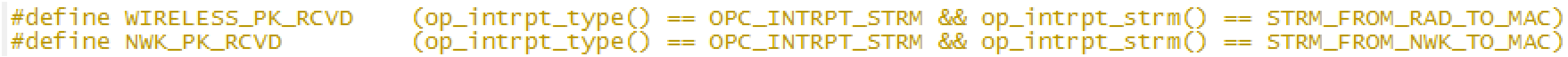
- **Website:** www.opnet.com (now *Riverbed*)
- Commercial software [expansive, but academia-supported]
  - MIT graduate spin-off started in 1986
- C-based
- **GUI-oriented**
  - Possibility of graphical design via state machines
  - Users can drag-and-drop necessary components and edit them

# OPNET: Example (1/2)

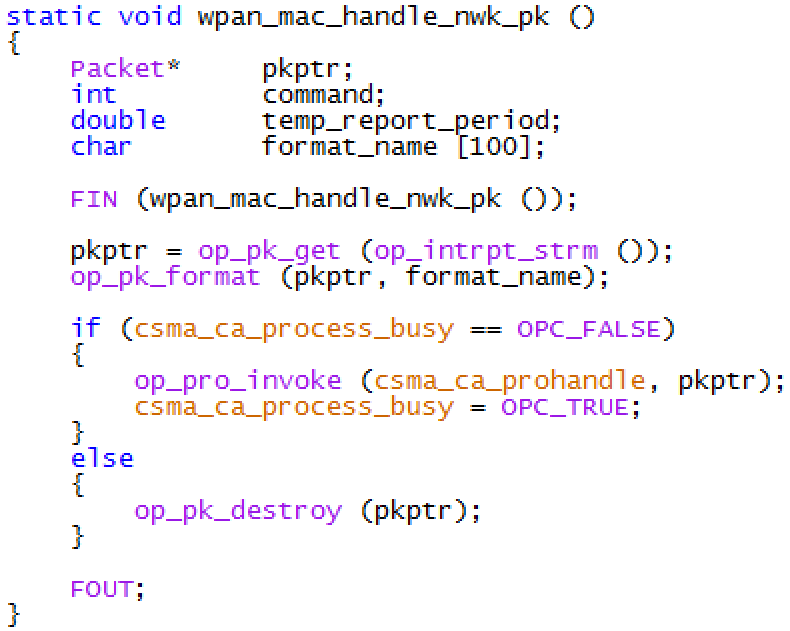
Simplified state machine for IEEE 802.15.3 MAC


(WIRELESS_PK_RCVD)/wpan_mac_handle_wireless_pk ()
(TX_FAILED)/wpan_handle_pkt_transmission_failure ()
init
active
(default)
1 / 0
1 / 2
(NWK_PK_RCVD)/wpan_mac_handle_nwk_pk ()
(TX_DONE)/wpan_handle_pkt_transmission_success ()

# OPNET: Example (2/2)



```
#define WIRELESS_PK_RCVD     (op_intrpt_type() == OPC_INTRPT_STRM && op_intrpt_strm() == STRM_FROM_RAD_TO_MAC)
#define NWK_PK_RCVD          (op_intrpt_type() == OPC_INTRPT_STRM && op_intrpt_strm() == STRM_FROM_NWK_TO_MAC)
```



```
static void wpan_mac_handle_nwk_pk ()
{
    Packet*      pkptr;
    int          command;
    double       temp_report_period;
    char         format_name [100];

    FIN (wpan_mac_handle_nwk_pk ());

    pkptr = op_pk_get (op_intrpt_strm ());
    op_pk_format (pkptr, format_name);

    if (csma_ca_process_busy == OPC_FALSE)
    {
        op_pro_invoke (csma_ca_prohandle, pkptr);
        csma_ca_process_busy = OPC_TRUE;
    }
    else
    {
        op_pk_destroy (pkptr);
    }

    FOUT;
}
```

# OmNet++: Overview

- **Website:** http://www.omnetpp.org
- Not open source, but free for academia
- Written in C++
- Good GUI
- Not a simulator per-se but a simulation framework
- Specific wireless networking modules built
    - Castallia, MiXiM, INETMANET, Oversim, …

# NS2: Overview

- **Website**: http://www.isi.edu/nsnam/ns/
- Open source
- C++ (module design)/ObjectTcl (simulation scenario design)
- NS2 started in 2009 and no longer maintained
  - Started as NS1 in around 1995 (but traced back to 1989)
- Lawrence Berkeley National Laboratory development
  - Sally Floyd (Random Early Detection co-inventor)
- Split in modules for each layer [PHY up to Application]
  - A lot of them!

- **Cons**
  - X000,000 lines of code
  - Buggy and difficult to learn [large community of developers]

# NS3: Overview

- **Website**: http://www.nsnam.org
- Open source
- NS3 is a follow-up to NS2 (duh!)
  - But not backward-compatible with NS2
- Simulations using using C++/Python/Waf
- Current release 3.19 [as of January 2014]

- **Cons**
  - Many well developed NS2 modules are (still) not available in NS3

- http://www.nsnam.org/tutorials/ns-3-tutorial-tunis-apr09.pdf

# NS3: A quick walk through

1. **Topology**
    1. Setting nodes in space
2. **Model definition**
    1. UDP/TCP/WiFi/LTE/MANET/…
3. **Node definition**
    1. P2P/Wireless/Wired/Channel/Packet size
4. **Execution**
5. **Analysis**
    1. Statistical data handling (octave/R)
    2. Plotting (e.g. gnuplot)
6. **Adapt**
    1. Go to step X

Let’s jump to a new presentation…

# Part 3: SDR

# Literature on Signals and Systems

- **Theory**
  - Andrea Goldsmith, **Wireless Communications**, Cambridge University Press (2005)
  - Ted Rappaport, **Wireless communications: principles and practice**, Prentice Hall (1996)
  - John Proakis, **Digital Communications**, Mcgraw-Hill (2008)
  - Mark Wickert, **Signals and Systems For Dummies**, (2013)

# Literature on Signals and Systems

- **Practice**
  - **http://www.desktopsdr.com/**
    - **Free book** plus **free examples**
    - Goes through all the math with examples
  - **MATLAB Communications Toolbox**
  - C. Richard Johnson Jr., **Software Receiver Design: Build Your Own Digital Communication System In Five Easy Steps,** Cambridge University Press (2011)

# SDR Assignment: FM receiver

- Exercise for next week:
  - http://www.eas.uccs.edu/~mwickert/ece4670/lecture_notes/Lab6.pdf
    - Section 5 and exercise 1 from section 5.3
    - **For other tips see also:**https://nl.mathworks.com/help/supportpkg/rtlsdrradio/examples/fm-broadcast-receiver.html