Wi-Fi Module in ns-3

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Outline

- Supported Features
- Architecture
- Using Wi-Fi Module
- FAQs (using Wi-Fi)
- Future work in 2014

Wi-Fi Module Features

Wi-Fi Module Features

- DCF implementation (Basic + RTS/CTS)
- 802.11 a/b/g
- QoS support (EDCA only)
- Some 802.11n (block ACK, frame aggregation)
- Infrastructure and ad-hoc modes
- Rate adaptation algorithms
- Channel models
- Mobility models

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Wi-Fi Module Architecture

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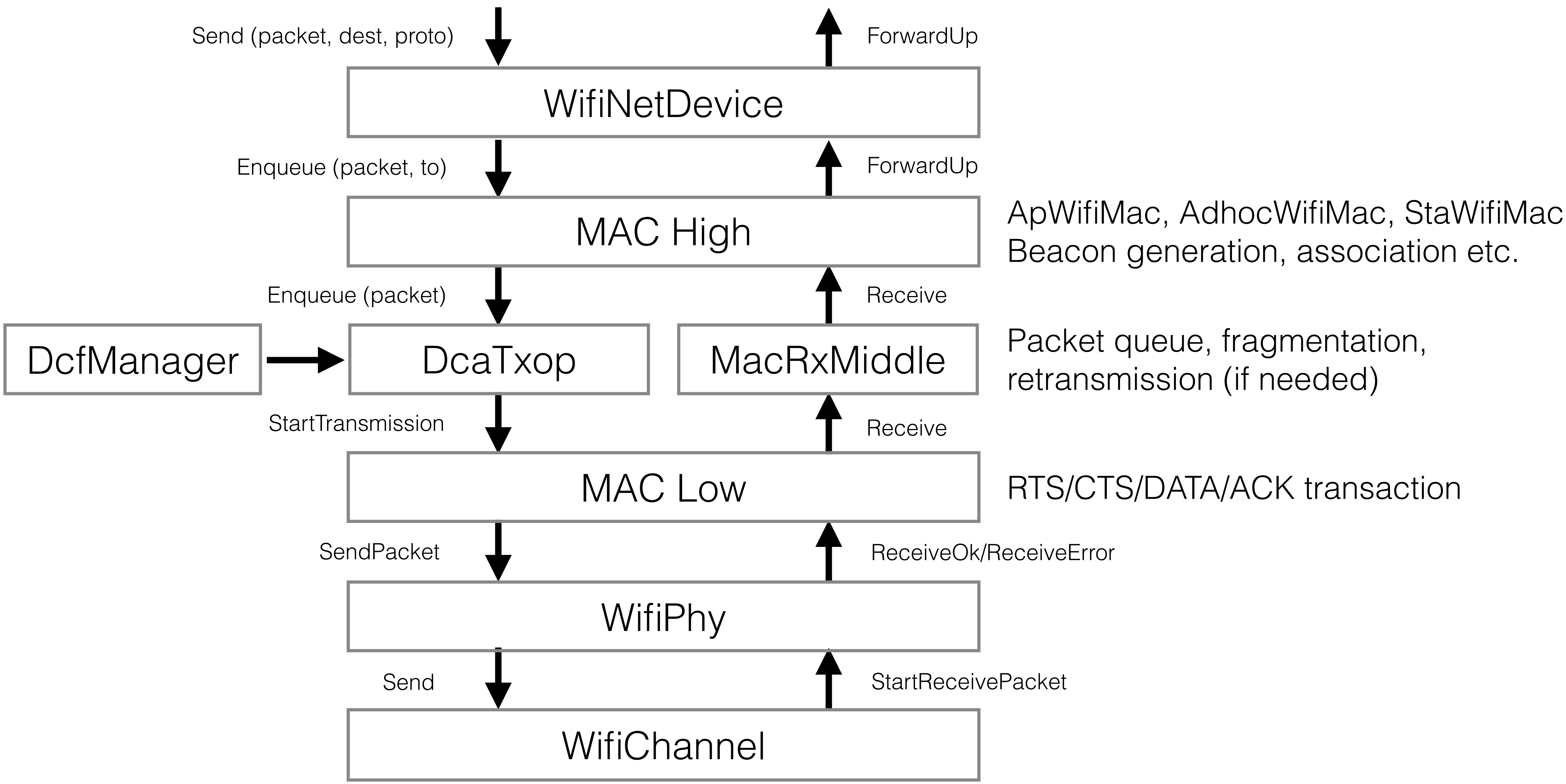
Wi-Fi Module Architecture

- PHY layer model
- MAC low models: implement DCF and EDCA
- MAC high models
    - Specialized models: ad-hoc and infrastructure
- Rate control algorithms

Wi-Fi Module Architecture



For more detailed info, see ns-3 model.

MAC High

- Presently, three MAC high models
  - AdhocWifiMac: simplest one
  - ApWifiMac: beacon, associations by STAs
  - StaWifiMac: association based on beacons
- All inherit from RegularWifiMac, which handles QoS and non-QoS support

MAC Low

- Three components
- MacLow
  - RTS/CTS/DATA/ACK transactions
- DcfManager
  - implements the DCF
- DcaTxop and EdcaTxopN:
  - One for NQoS, the other for QoS
  - Packet queue
  - Fragmentation/Retransmissions

Wi-Fi Rate Adaptation

- Both low-latency and high-latency Rate Adaptation is supported
- Algorithms in real devices (partial list)
  - ArfWifiManager (default of WifiHelper)
  - OnoeWifiManager
  - ConstantRateWifiManager
- Algorithms in literature (partial list)
  - IdealWifiManager
  - AarfWifiManager
  - AmrrWifiManager

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Wi-Fi PHY

- Work at packet (frame) level
- Different models available
  - PhySimWifi — symbol-level, too slow for practical use
  - YansWifiPhy — default & most widely used
  - SpectrumWifiPhy (unfinished model, work stalled)
    - Models power spectral density of each transmission
    - Supports inter-technology interference
- Some details are not implemented (e.g. preamble/capture effect)

Synchronization Model

- Energy Detection only
  - no preamble detection model
  - no AGC model
- Sync on first RX with energy > threshold
- Collision: the error model would likely drop the packet
- No capture effect: won't re-sync on a stronger packet

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SNIR Model [1]

- Each TX attempt modeled with single power value
- SINR calculation assuming gaussian interference
- «Chunk» error rate model
    - Basically, packet error rate model
    - But accounts for partially overlapping packets in time
    - «chunk»: interval of RX with constant SINR
- Orthogonal channel model only
    - No adjacent channel interference model

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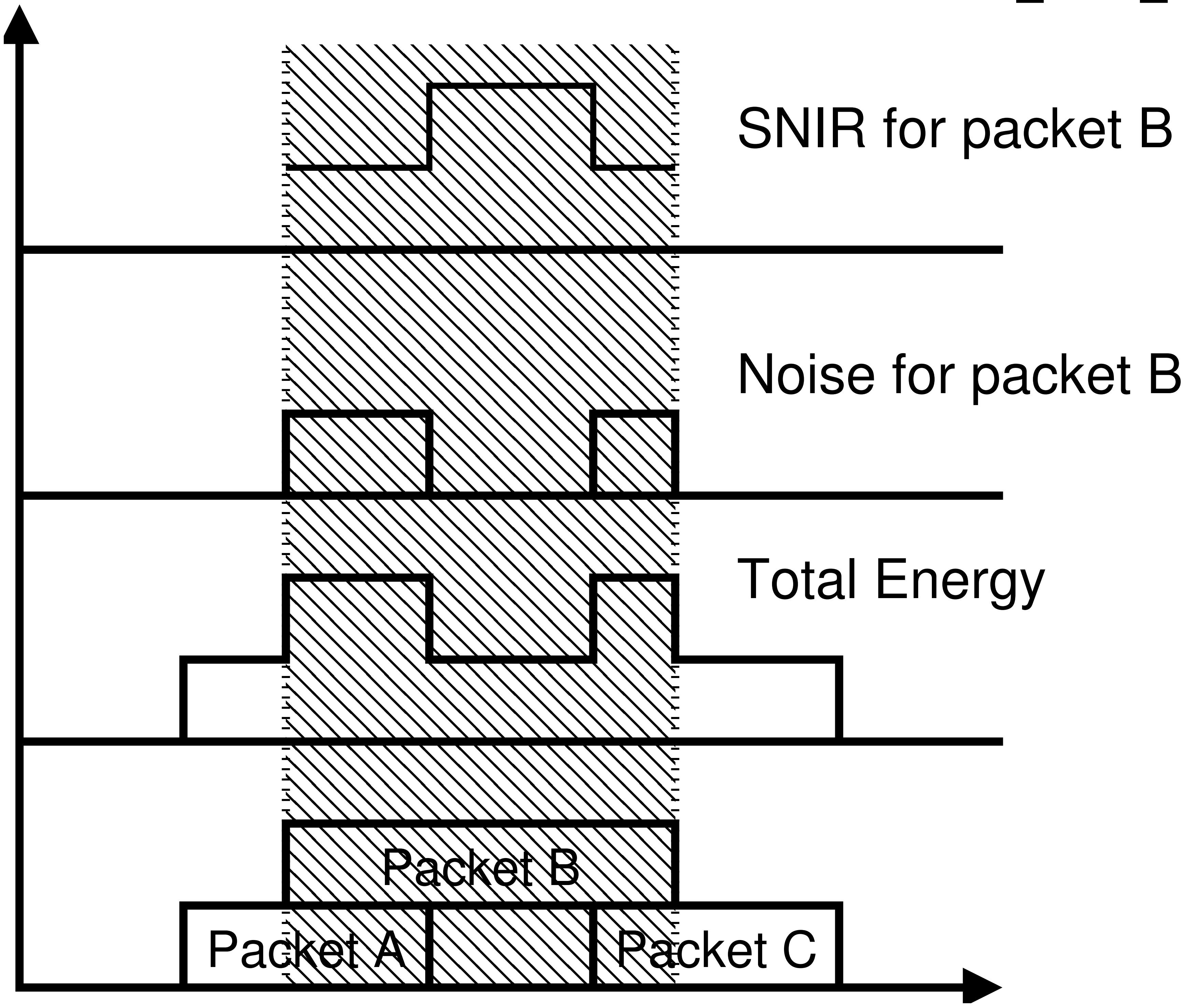
SNIR Calculation [1]



Error Rate Models

- One 802.11b model
  - Validated with Clear Channel experiments
- Two OFDM models
  - YANS model — A bit optimistic
  - NIST model — Better match with experiment [2]

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Using Wi-Fi in ns-3

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Setting up Wi-Fi Simulations

- Nodes
- Wi-Fi
- Mobility
- Routing
- Internet stack
- Application

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Decisions

- Wi-Fi Standard 802.11a/b/g
- QoS or non-QoS
- Infrastructure or ad hoc
- Rate control
- WifiChannel — propagation loss/delay model
- Routing
- Mobility model

Sample Code

```
NodeContainer c;
c.Create (2);

WifiHelper wifi;
wifi.SetStandard (WIFI_PHY_STANDARD_80211a);

// Set to a non-QoS upper mac
NqosWifiMacHelper wifiMac = NqosWifiMacHelper::Default ();

// Set it to adhoc mode
wifiMac.SetType ("ns3::AdhocWifiMac");

// Set Wi-Fi rate manager
std::string phyMode ("OfdmRate54Mbps");
wifi.SetRemoteStationManager ("ns3::ConstantRateWifiManager",
                              "DataMode",StringValue (phyMode),
                              "ControlMode",StringValue (phyMode));
```

```
YansWifiPhyHelper wifiPhy =  YansWifiPhyHelper::Default ();
// ns-3 supports RadioTap and Prism tracing extensions for 802.11
wifiPhy.SetPcapDataLinkType (YansWifiPhyHelper::DLT_IEEE802_11_RADIO);

YansWifiChannelHelper wifiChannel;
wifiChannel.SetPropagationDelay ("ns3::ConstantSpeedPropagationDelayModel");
wifiChannel.AddPropagationLoss ("ns3::LogDistancePropagationLossModel",
                                "Exponent", DoubleValue (3.0));
wifiPhy.SetChannel (wifiChannel.Create ());

NetDeviceContainer devices = wifi.Install (wifiPhy, wifiMac, c);

// Enable PCAP
wifiPhy.EnablePcap ("wifi-adhoc", devices);

// Configure mobility
MobilityHelper mobility;
Ptr<ListPositionAllocator> posAlloc = CreateObject<ListPositionAllocator> ();
posAlloc->Add (Vector (0.0, 0.0, 0.0));
posAlloc->Add (Vector (5.0, 0.0, 0.0));
mobility.SetPositionAllocator (posAlloc);
mobility.SetMobilityModel ("ns3::ConstantPositionMobilityModel");
mobility.Install (c);
```

Selecting Wi-Fi Standard

```
NodeContainer c;
c.Create (2);

WifiHelper wifi;
wifi.SetStandard (WIFI_PHY_STANDARD_80211a);
```

- Create WifiHelper
- WifiHelper::SetStandard (enum WifiPhyStandard s);

WIFI_PHY_STANDARD_80211a	OFDM PHY 5GH
WIFI_PHY_STANDARD_80211b	DSSS PHY and HR/DSSS PHY
WIFI_PHY_STANDARD_80211g	EPR-OFDM PHY
etc.	

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QoS or non-QoS

```
NodeContainer c;
c.Create (2);

WifiHelper wifi;
wifi.SetStandard (WIFI_PHY_STANDARD_80211a);

// Set to a non-QoS upper mac
NqosWifiMacHelper wifiMac = NqosWifiMacHelper::Default ();
```

- NqosWifiMacHelper for non-QoS
- QosWifiMacHelper for QoS

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Ad hoc or Infrastructure

```
NodeContainer c;
c.Create (2);

WifiHelper wifi;
wifi.SetStandard (WIFI_PHY_STANDARD_80211a);

// Set to a non-QoS upper mac
NqosWifiMacHelper wifiMac = NqosWifiMacHelper::Default ();

// Set it to adhoc mode
wifiMac.SetType ("ns3::AdhocWifiMac");
```

ns3::AdhocWifiMac	simplest, no beacon/assoc.
ns3::StaWifiMac	generates beacon, assoc. resp.
ns3::ApWifiMac	assoc. request

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Rate Manager

```
// Set Wi-Fi rate manager
std::string phyMode ("OfdmRate54Mbps");
wifi.SetRemoteStationManager ("ns3::ConstantRateWifiManager",
                              "DataMode",StringValue (phyMode),
                              "ControlMode",StringValue (phyMode));
```

- Select Wi-Fi rate manager
- This example — constant rate
  - Unicast DATA @ 54Mbps
  - Control “request” @ 54Mbps

802.11a	OfdmRateXXMbps
802.11b	DsssRateXXMbps
802.11g	ErpOfdmRateXXMbps
etc.	

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Rate Manager (cont.)

- For Non-unicast DATA

```
Config::SetDefault(“ns3::WifiRemoteStationManager::NonUnicastMode”,
                   StringValue (phyMode));
```

- Control “reply” modes are not directly set (see [3])
- Other rate managers may not require manual setting as they automatically select the “best” rate

Rate Manager (cont.)

- Other interesting attributes
  - MaxSsrc — retransmission limit for RTS
  - MaxSlrc — retransmission limit for DATA
  - RtsCtsThreshold
  - FragmentationThreshold
- May not have effect on some rate control algorithms

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WifiPhy

```
YansWifiPhyHelper wifiPhy =  YansWifiPhyHelper::Default ();
```

- Select ErrorRateModel here
- YansWifiPhyHelper::Default () is NistErrorRateModel
- To change to YansErrorRateModel, do
  YansWifiPhyHelper::SetErrorRateModel (“ns3::YansErrorRateModel”);
- Nist/Yans ErrorRateModels are for ERP-OFDM and OFDM, both models call DsssErrorRateModel automatically for DSSS

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WifiPhy

```
YansWifiPhyHelper wifiPhy =  YansWifiPhyHelper::Default ();
// ns-3 supports RadioTap and Prism tracing extensions for 802.11
wifiPhy.SetPcapDataLinkType (YansWifiPhyHelper::DLT_IEEE802_11_RADIO);
```

- (Optional) set PCAP data link type
- Only “set” PCAP data link type, “enable” later

DLT_IEEE802_11 (default)	802.11 headers
DLT_PRISM_HEADER	Include Prism monitor mode info.
DLT_IEEE802_11_RADIO	Include Radiotap link layer info.

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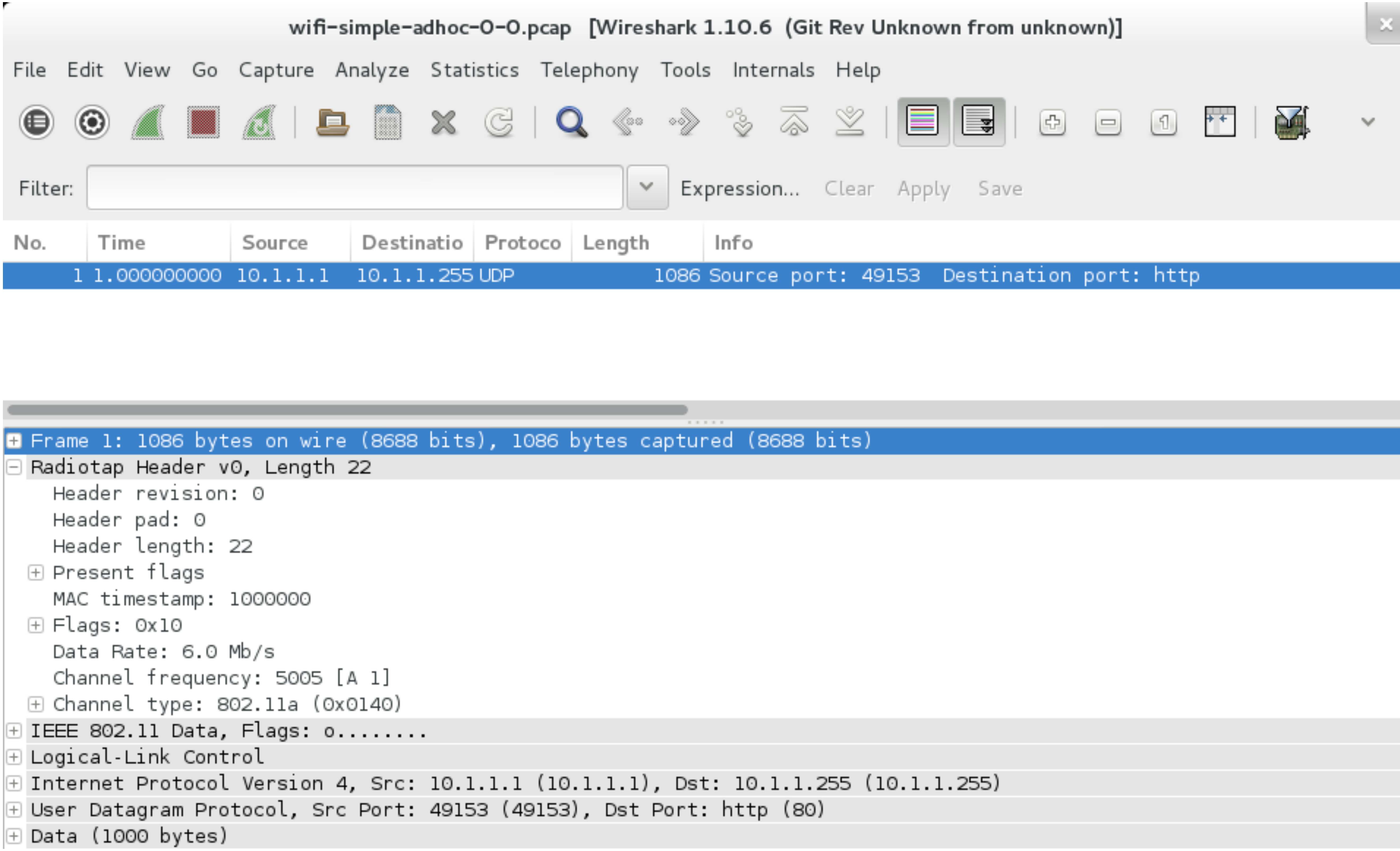

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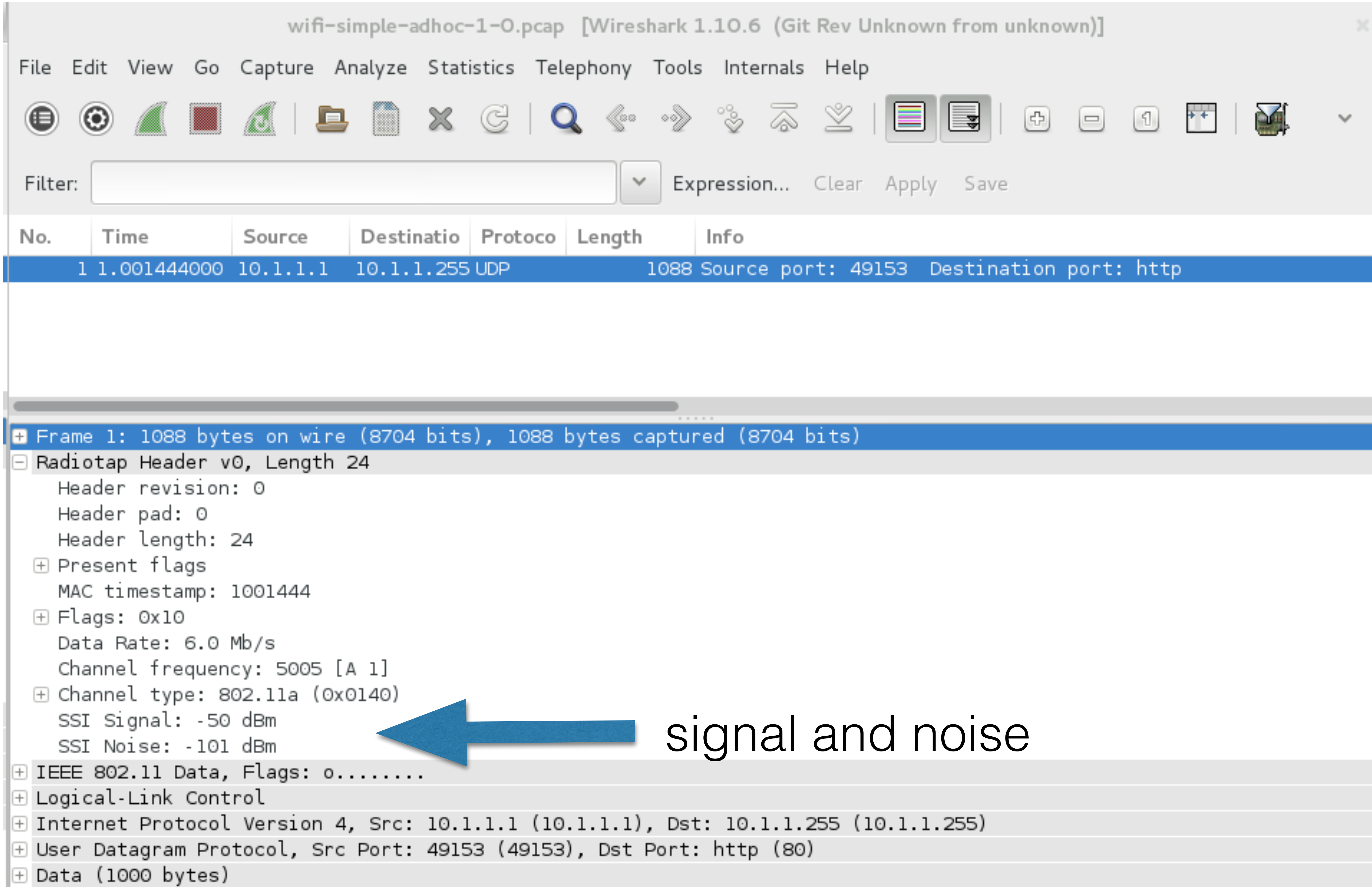
wifi-simple-adhoc-1-0.pcap [Wireshark 1.10.6 (Git Rev Unknown from unknown)]
File Edit View Go Capture Analyze Statistics Telephony Tools Internals Help
Filter:
Expression... Clear Apply Save
No. Time Source Destinatio Protoco Length Info
1 1.001444000 10.1.1.1 10.1.1.255 UDP 1088 Source port: 49153 Destination port: http
Frame 1: 1088 bytes on wire (8704 bits), 1088 bytes captured (8704 bits)
Radiotap Header v0, Length 24
Header revision: 0
Header pad: 0
Header length: 24
Present flags
MAC timestamp: 1001444
Flags: 0x10
Data Rate: 6.0 Mb/s
Channel frequency: 5005 [A 1]
Channel type: 802.11a (0x0140)
SSI Signal: -50 dBm
SSI Noise: -101 dBm
IEEE 802.11 Data, Flags: o........
Logical-Link Control
Internet Protocol Version 4, Src: 10.1.1.1 (10.1.1.1), Dst: 10.1.1.255 (10.1.1.255)
User Datagram Protocol, Src Port: 49153 (49153), Dst Port: http (80)
Data (1000 bytes)
signal and noise

WifiChannel (Loss/Delay)

```
YansWifiChannelHelper wifiChannel;
wifiChannel.SetPropagationDelay ("ns3::ConstantSpeedPropagationDelayModel");
wifiChannel.AddPropagationLoss ("ns3::LogDistancePropagationLossModel",
                                "Exponent", DoubleValue (3.0));
wifiPhy.SetChannel (wifiChannel.Create ());
```

- “Blank” YansWifiChannelHelper
- Manually set PropogationDelayModel to ConstantSpeed
- Manually “add” LogDistancePropagationLossModel to the chain of PropagationLossModels
- ns3::YansWifiChannelHelper::Default () sets Delay to ConstantSpeed and <u>already has</u> LogDistance in the chain of PropagationLossModels (e.g. calling AddPropagationLoss again will add to the chain)

Wi-Fi Device

```
NetDeviceContainer devices = wifi.Install (wifiPhy, wifiMac, c);

// Enable PCAP
wifiPhy.EnablePcap ("wifi-adhoc", devices);
```

- Finally install the device on nodes
- Enable PCAP output if needed

Mobility Model

- Initial position (partial list)
  - List
  - RandomRectangle
- Mobility model (partial list)
  - Constant
  - Random Waypoint (see [6])

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Mobility Model — Initial

```
// Configure mobility
MobilityHelper mobility;
Ptr<ListPositionAllocator> posAlloc = CreateObject<ListPositionAllocator> ();
posAlloc->Add (Vector (0.0, 0.0, 0.0));
posAlloc->Add (Vector (5.0, 0.0, 0.0));
mobility.SetPositionAllocator (posAlloc);
mobility.SetMobilityModel ("ns3::ConstantPositionMobilityModel");
mobility.Install (c);
```

- Here: ListPositionAllocator
- Other options (partial list):
  - RandomRectanglePositionAllocator
  - GridPositionAllocator

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Mobility Model — Mobility

```
// Configure mobility
MobilityHelper mobility;
Ptr<ListPositionAllocator> posAlloc = CreateObject<ListPositionAllocator> ();
posAlloc->Add (Vector (0.0, 0.0, 0.0));
posAlloc->Add (Vector (5.0, 0.0, 0.0));
mobility.SetPositionAllocator (posAlloc);
mobility.SetMobilityModel ("ns3::ConstantPositionMobilityModel");
mobility.Install (c);
```

- Here: ConstantPositionMobilityModel
- Other options (partial list):
  - RandomWalk2dMobilityModel
  - RandomWaypointMobilityModel

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Others…

- Internet stack
- Routing
- Application
- Statistics e.g. FlowMonitor

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Routing Protocols

- Ad-hoc routing protocol examples (IPv4 only):
    - DSR
    - AODV
    - OLSR
- Different set up (see manet-routing-compare.cc)
- Some are sensitive to start time (more later)
- Also possible: calculate routes offline and use static routes

Frequently Asked Questions

Transmission Range

- Related questions:
    - How many nodes do I need?
    - Planned network (e.g. grid/linear)

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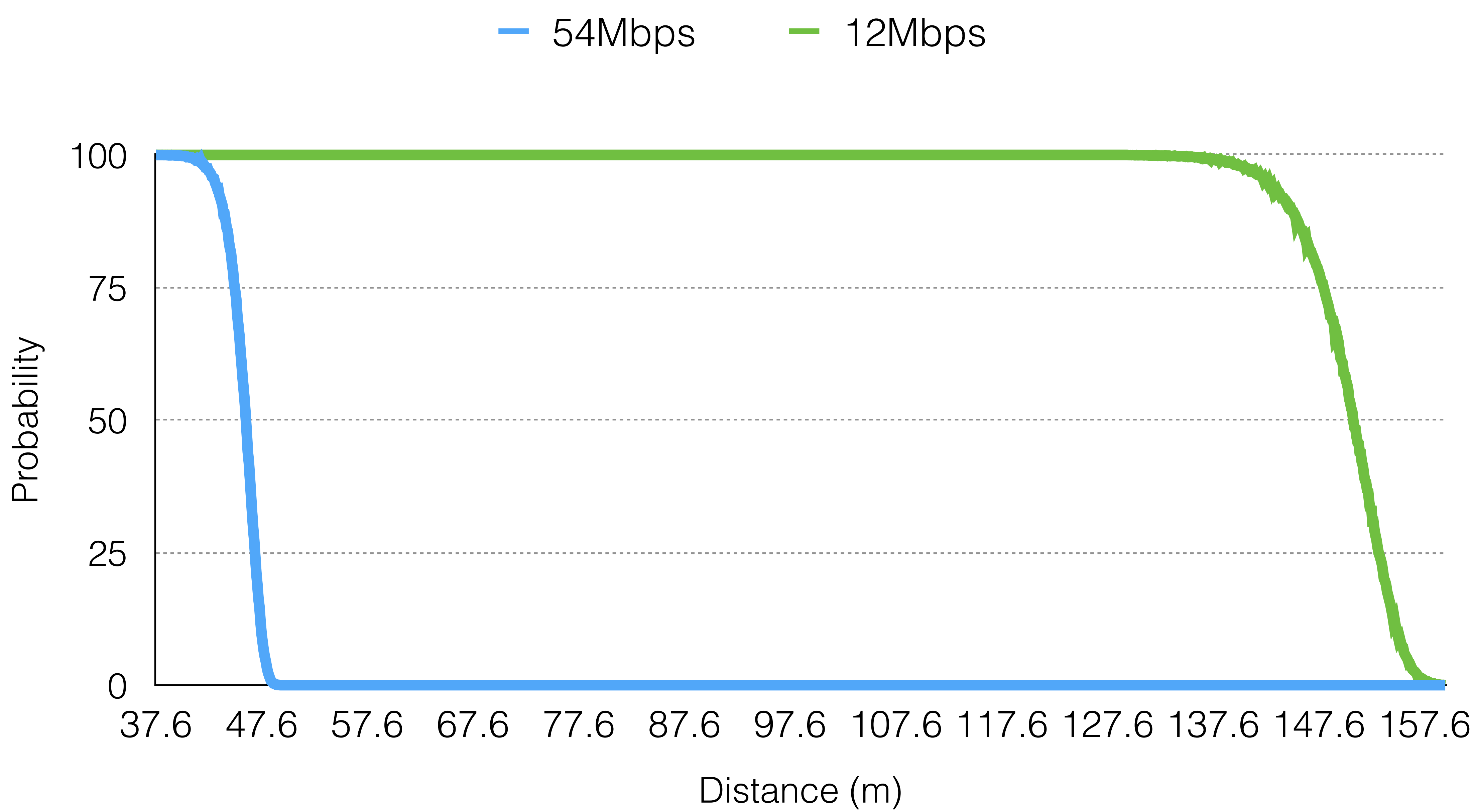
Transmission Range

- Depends on many factors
- Transmission mode (6Mbps vs. 54Mbps)
- Propagation loss model
- Frame size (big vs. small)
- etc.

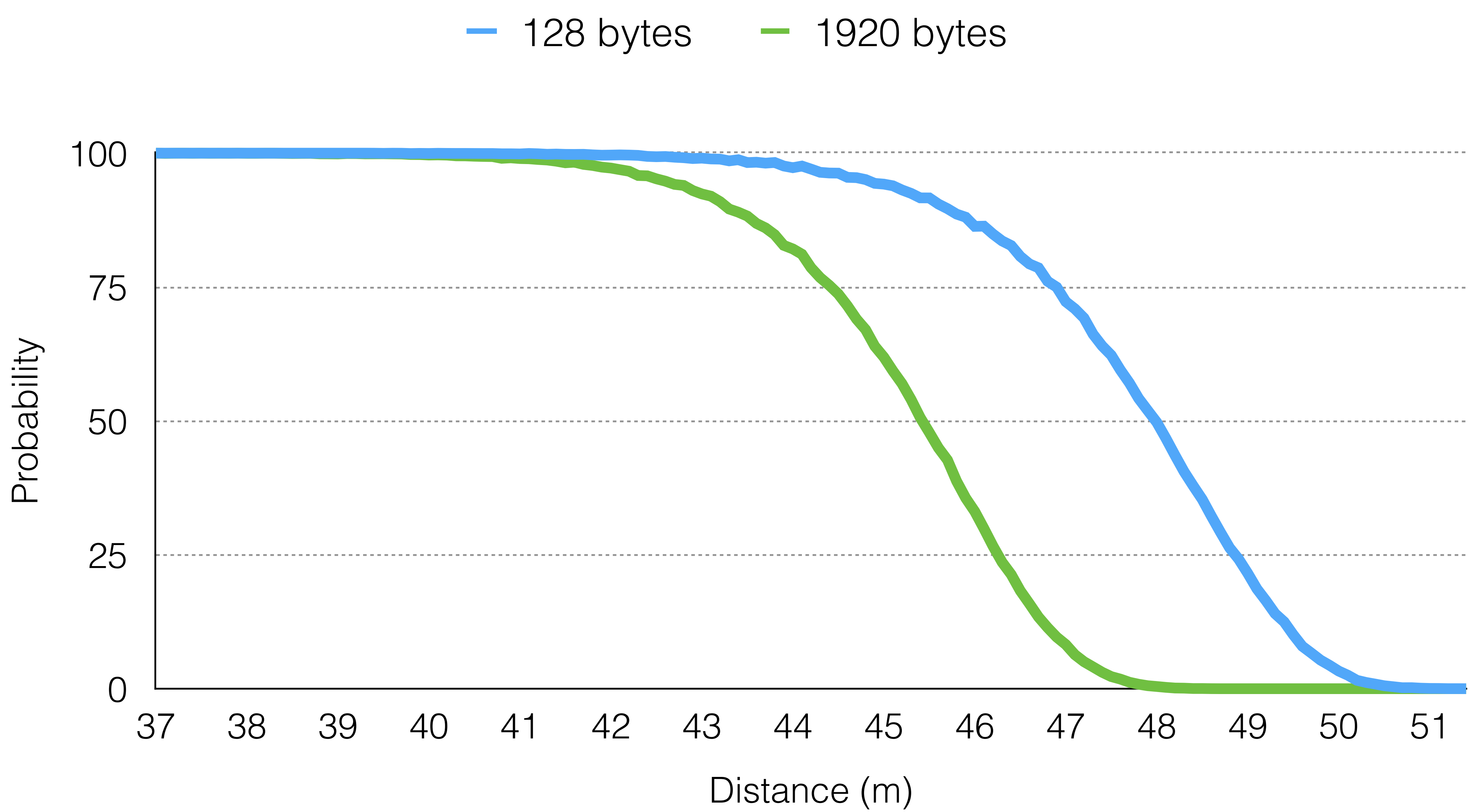
Transmission Range (cont.)

- Simple set up with two nodes — source and sink
- Source — broadcast UDP @100pkt/s for 1000s
- Places the two nodes at different distances, run the application then count the number of packets received at different distances

Changing Wi-Fi Mode



Changing Frame Size



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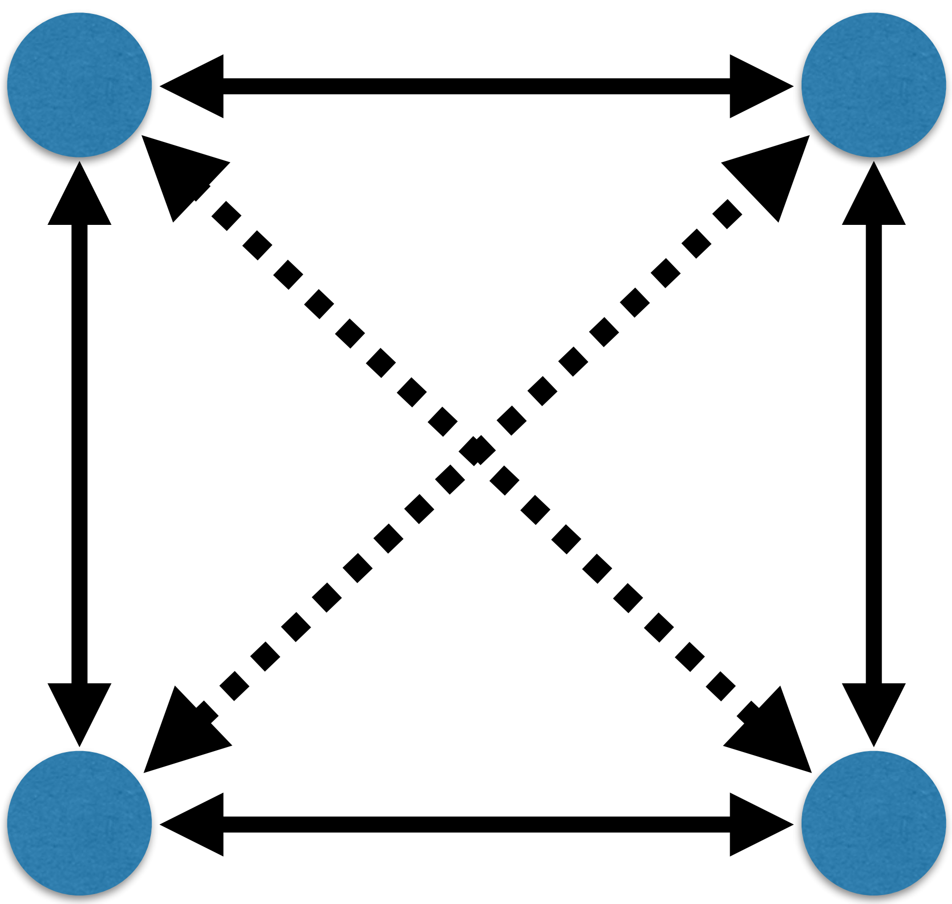
Simulation Setup

- Higher data rate = shorter range
  - e.g. 802.11g @ 54Mbps ~ 40 meters
- Need (very!) high density network
- More nodes = more simulation time
  - Simulation can be really, really slow

Implications on Routing

- Broadcast is sent using the slowest rate while unicast is usually sent using higher rate
- Common: build routes using broadcast, send data using unicast
- Route is OK when “build”, bad when “use”

Examples (Grid Network)



- Select propagation loss model
- e.g. log-distance is tricky
- Do you want diagonal links?
- No? Range or matrix may work
- Also applies to linear network

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Propagation Loss Models

- Some propagation loss models have parameters that depend on the channel frequency
  - e.g. reference loss of log-distance
- Check for frequency-dependent variables!
- Most default values of ns-3 are for 802.11a (5 GHz)
- Setting up the loss model correctly

Wi-Fi Rate Manager

- Multiple Wi-Fi rate managers are available
- Depends on your simulation setup
- Most common is probably ConstantRate
  - Settable: rate for Data and Control (RTS)
  - CTS/ACK are not “directly” settable (see [3])
  - Rate of non-unicast is set at WifiRateManager

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Setting up Applications

- Timing is very important in wireless simulations
- Setting multiple applications to start at the same time is not a good idea in general (ApplicationContainer::Start () sets all in container)
- Nodes are likely to initiate route building process at the exact same time
  - collision is almost guaranteed

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Maximum “Application” Rate

- The maximum achievable “application” data rate is not the same as the “Wi-Fi” rate due to:
    - Timing (IFS)
    - RTS/CTS/ACK
    - Multihop (shared medium)
- Avoid setting application rate == Wi-Fi rate

Mixed-mode Simulation

- Currently 802.11g is compatible with 802.11b
- E.g. timing
- DSSS preamble + OFDM frame is not supported

Interesting Examples

- examples/wireless/wifi-simple-adhoc.cc
  - Simple ad hoc with two nodes (fixed RSS loss)
- examples/wireless/wifi-simple-infra.cc
  - Infrastructure mode (1 AP + 1 STA)
- examples/routing/manet-routing-compare.cc
  - Setting up different routing protocols

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Future Work to Expect in 2014

- Wi-Fi Sleep Mode
- A-MPDU
- 802.11n

References and other interesting papers

1. M. Lacage, T. Henderson, “Yet Another Network Simulator,” Proc. 2006 Workshop on ns-2, 2006

2. G. Pei, T. Henderson, “Validation of OFDM Error Rate Model in ns-3,” Tech. Rep. Boeing Research Technology, 2010

3. http://www.nsnam.org/wiki/HOWTO_add_basic_rates_to_802.11

4. M. Al-Bado, C. Sengul, R. Merz, “What Details are Needed for Wireless Simulations? — A Study of a Site-Specific Indoor Wireless Model,” INFOCOM, 2012

5. http://dsn.tm.kit.edu/english/ns3-physim.php

6. J. Yoon, M. Liu, B. Noble, “Random Waypoint Considered Harmful,” INFOCOM, 2003