RT-WLAN: A Soft Real-Time Wireless LAN

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WLAN in the Market

- **Current WLAN Standards**

Standard	Max. Bandwidth	Range	Band	Non standard enhancements
IEEE 802.11b	11 Mbps	Outdoors: 500m Indoors: 150m	2.4 GHz	802.11b+ 22 Mbps
IEEE 802.11a	54 Mbps	Outdoors: 350m Indoors: 100m	5 GHz	Turbo mode: 108 Mbps

- **Reasons for popularity**
  - High Throughput
  - Affordable
  - Integrated WLAN devices
    - Tablet PCs: Compaq, Acer
    - PDAs: Toshiba, Palm, Compaq
    - Cellphones: Symbol, Spectralink
    - Laptops: IBM, HP, Apple,Toshiba, Dell, Compaq, Gateway

802.11 Basics

- Shared medium: Uplink and downlink
- Same MAC protocol at every device (Access Point or user terminal)
- Two modes of operation
  - DCF (Distributed Coordination Function): common mode
    - Distributed approach to access the channel using CSMA/CA
  - PCF (Point Coordination Function): mode not included in inter-operability standard by Wi-Fi Alliance
    - Users polled by Access Point
- Ethernet-like MAC protocol
  - Carrier sense before sending
  - Binary Exponential Backoff on contention

WLAN Research

- **MAC enhancements for Quality of Service (QoS)**
  – 802.11e: VoIP, video conferencing, streaming media
- **Improved Physical Layer: Higher rate and longer range**
  – 802.11g: higher speed but backward compatible to 802.11b
- **Security and Authentication**
  – WEP (Wired-Equivalent Privacy) found to be broken
  – 802.11i: interim standard WPA (Wi-Fi protected access)
- **Fair channel access**
  – crucial in commercial deployments

Why Real-Time WLAN?

IEEE 802.11 MAC

- It has two modes: DCF (mandatory) and PCF (optional).
- Only the DCF is implemented.
- DCF is contention-based (CSMA/CA).

- Two problems under the DCF:
  - Contention-based nature $\Longrightarrow$ Unpredictable delay of frame transmissions.
  - Can not support prioritized transmission of real-time traffic.

Problem Statement

FACTS

- The new E-DCF is being proposed, but not finalized yet.
- So, DCF-based 802.11 products are expected to continue their dominance of the market.

OBJECTIVE

- Support real-time applications in the existing 802.11 DCF systems, in particular, the one using the popular ORiNOCO devices.

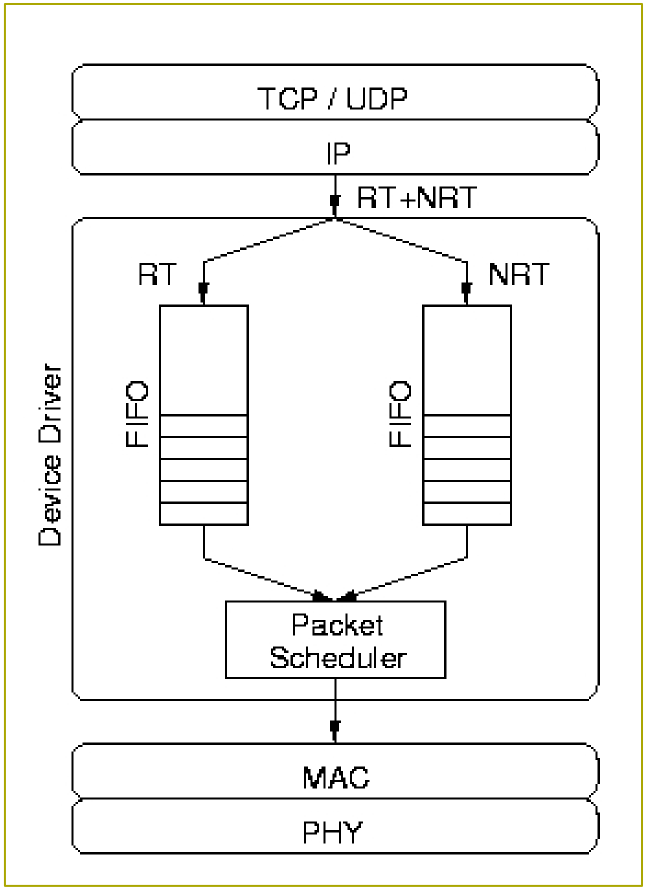
Our Approach

RT–WLAN

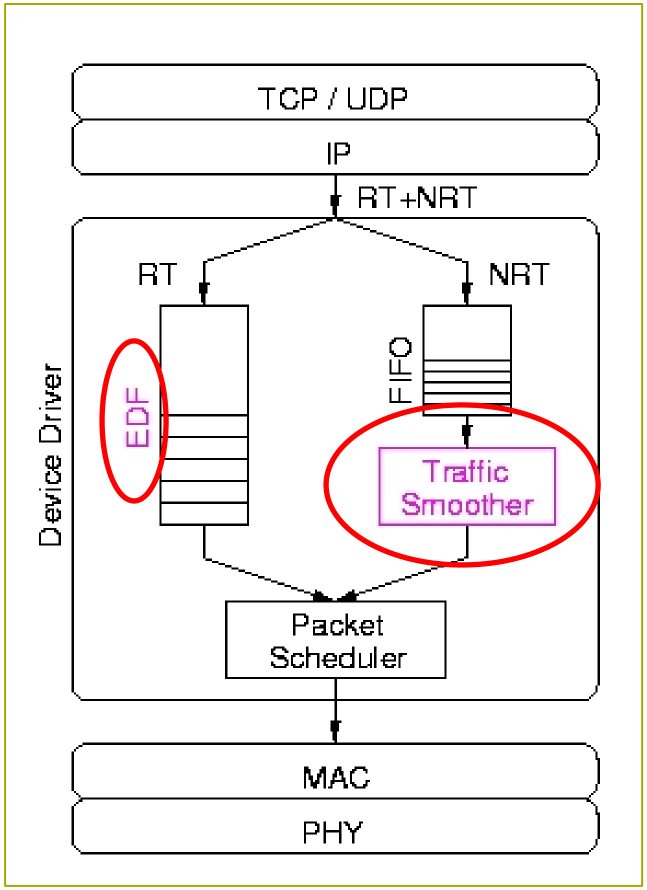
- New ORiNOCO Linux device driver with real-time extensions:
  - It does not require any change to the OS kernel!
  - It does not require any change to the MAC firmware!
  - Plug-in-and-Play!
- Two key extensions:
  - Assign higher priority to the RT (real-time) queue and apply the EDF (Earliest Deadline First) policy to the RT queue.
  - Apply adaptive traffic smoothing to the NRT (non-real-time) traffic.

Device Driver Architecture

Original ORiNOCO Driver



RT-WLAN



The RT Queue

Application Level

- API: "*set_priority(int packet_type, double relative_deadline)*"*.*
- For RT packets: *packet_type* is 1.

Device Driver Level

- Calculate the absolute deadline for each RT packet based on *relative_deadline*.
- EDF Policy:
  - Each RT packet is inserted into the RT queue according to its absolution deadline.
  - RT packets are served in the order of their positions in the RT queue from head to tail.

The NRT Queue

Application Level

- API: "*set_priority(int packet_type, double relative_deadline)*".
- For NRT packets: *packet_type* is 0 and *relative_deadline* is ignored.

Device Driver Level

- FIFO Policy:
  - NRT packets are served in the order they are en-queued.
- However, before an NRT packet is actually de-queued, it will be passed through an adaptive traffic smoother.

Adaptive Traffic Smoother

- It is a leaky-bucket regulator.

$$\text{Station Input Limit} = \frac{\text{CBD (Credit Bucket Depth)}}{\text{RP (Refreshing Period)}}$$

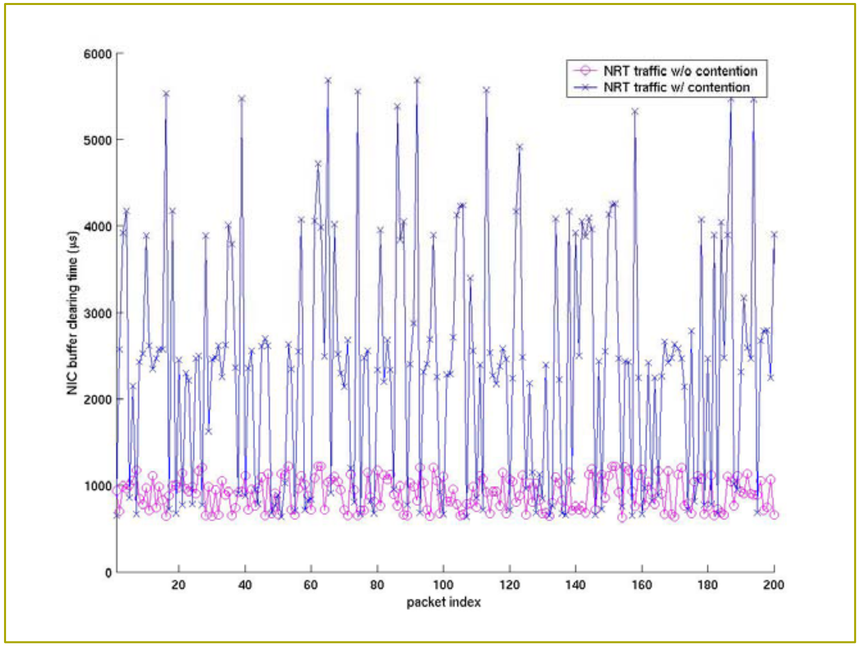
- HIMD (Harmonic-Increase and Multiplicative-Decrease)
  - Decreasing RP by a fixed constant δ every τ seconds
    $\Rightarrow$ Increasing the Station Input Limit harmonically.
  - Depleting CBD and doubling RT If network utilization is high
    $\Rightarrow$ Decreasing the Station Input Limit multiplicatively.
- So, it needs the feedback from a network utilization indicator.

Network Utilization Indicator

- Ethernet device drivers: use collision status report.
- RT-WLAN:
  - Collision status report is not supported in ORiNOCO driver.
  - So, we use NIC Buffer Clearing Time.

Test Results

- 'o' points: the benchmark case when there is no contention.
- 'x' points: two stations are contending for the medium.



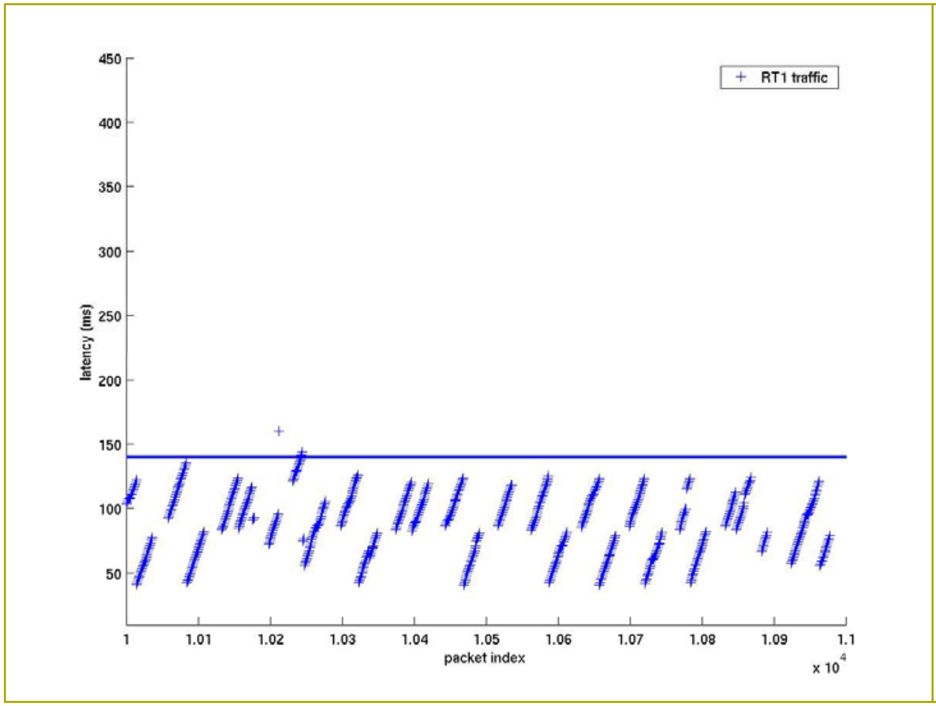
Experiment Scenario - I

Peer-To-Peer RT Streaming

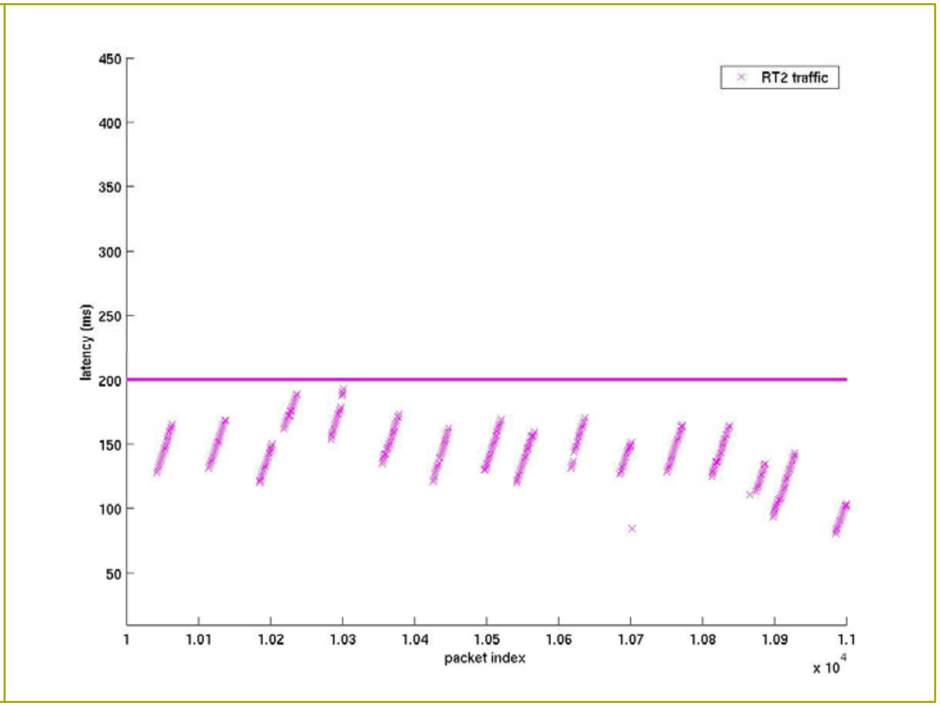
- To show the effects of applying EDF policy on the RT queue.
- Network Configuration
  - Two laptops are communicating with each other.
  - The transmitter has two RT traffic sources: RT1 and RT2.
- Station Configuration
  - Both laptops are using Agere ORiNOCO silver cards and are running in the IBSS ad hoc mode.

Latency Comparison (1)

RT1: *relative_deadline* = 140ms

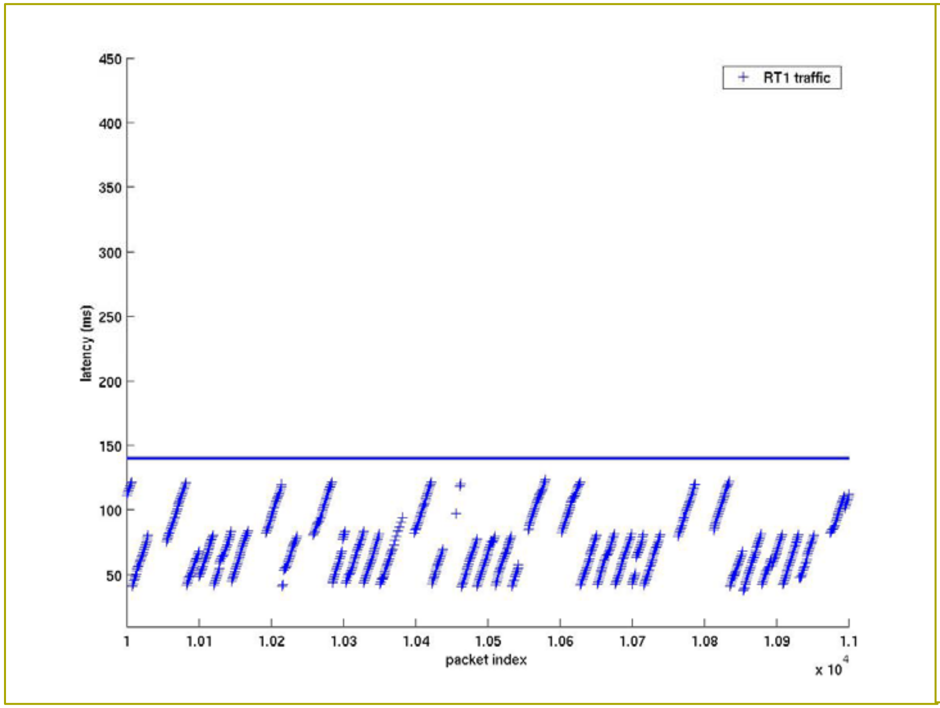


RT2: *relative_deadline* = 200ms

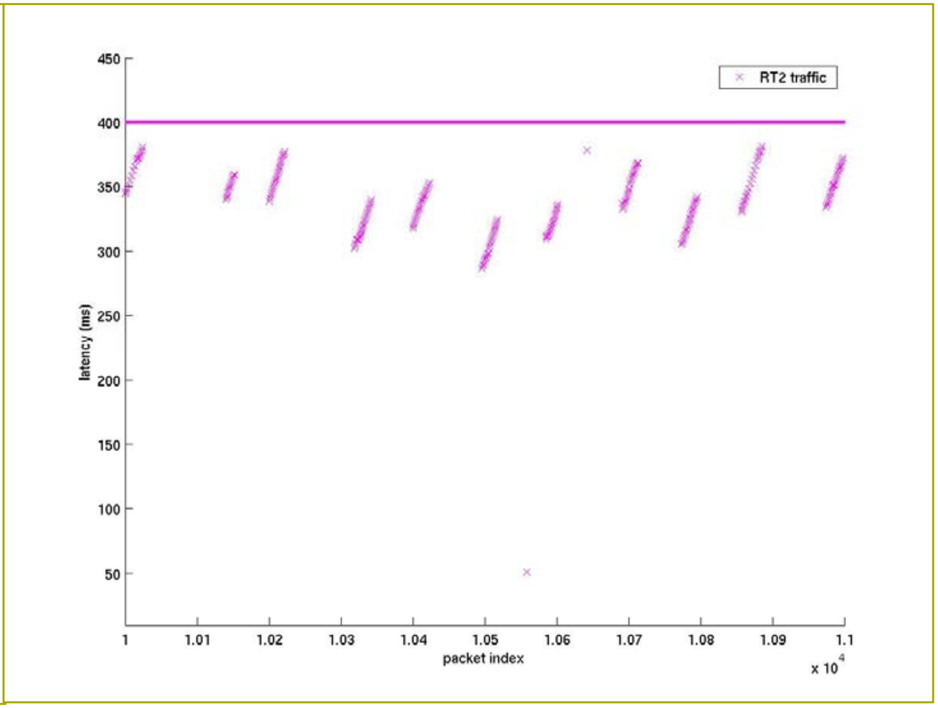


Latency Comparison (2)

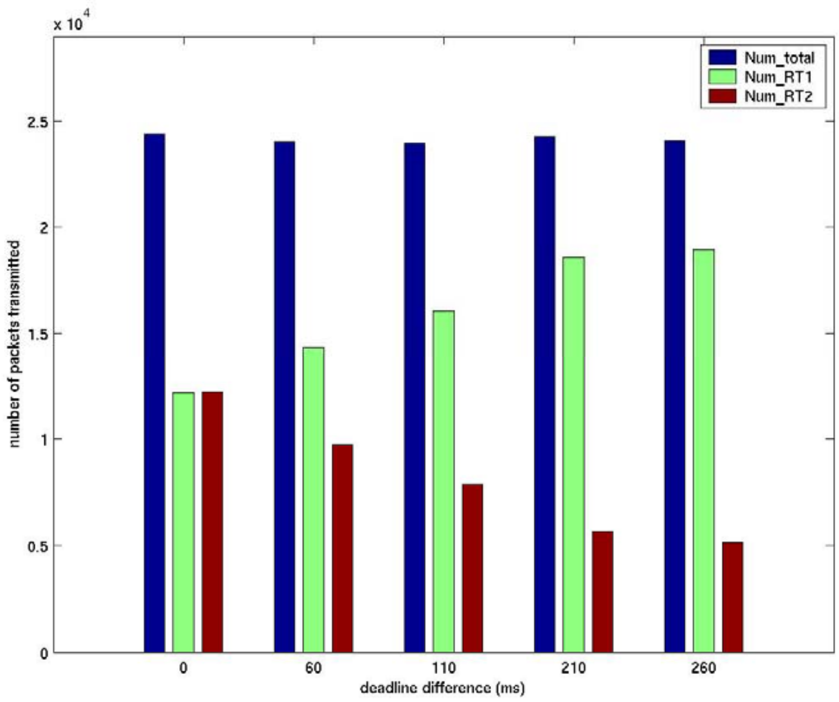
RT1: *relative_deadline* = 140ms



RT2: *relative_deadline* = 400ms



Throughput Comparison



OBSERVATIONS

- Zero deadline difference $\Rightarrow$ FIFO.
- Larger deadline difference $\Rightarrow$ RT1 is assigned higher transmission priority, and thus has more shares of bandwidth.

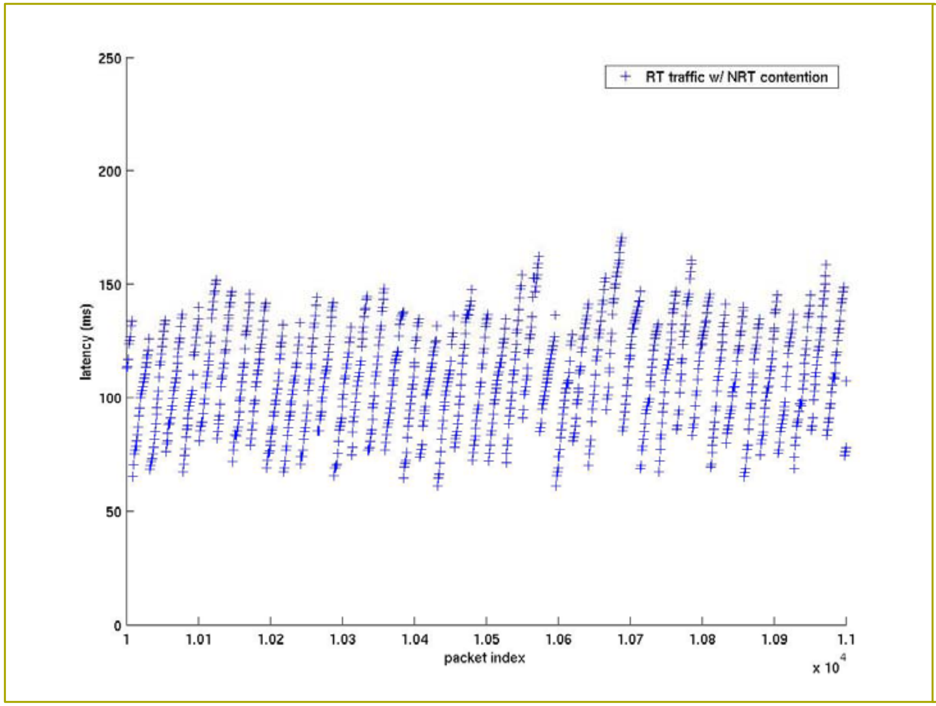
Experiment Scenario - II

RT Streaming in presence of 3rd-Party NRT Traffic

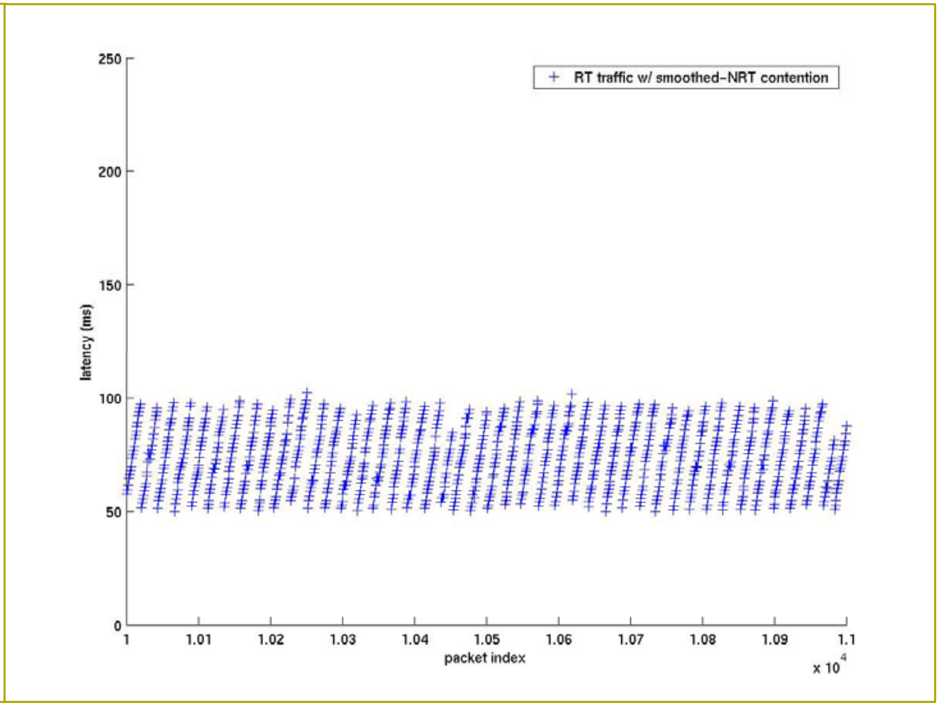
- To show the effects of applying adaptive traffic smoothing to the NRT traffic.
- Network Configuration
  - Three laptops are used.
  - Two laptops generate RT and NRT traffic, respectively, and the third one serves as the common receiver to both.
- Station Configuration
  - All three laptops are using Agere ORiNOCO silver cards and are running in the IBSS ad hoc mode.

Latency Comparison

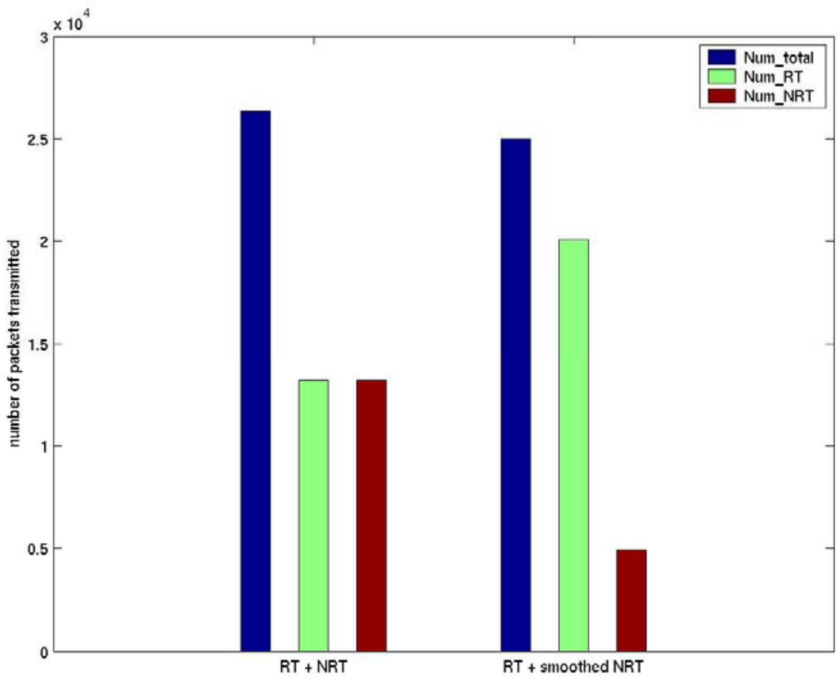
RT (+ NRT contention)



RT (+ smoothed NRT contention)



Throughput Comparison



OBSERVATIONS

- Without adaptive traffic smoothing ⇒ RT and NRT traffic share the bandwidth equally.
- Adaptive traffic smoothing ⇒ RT traffic has more shares of bandwidth, but 5% drop in total throughput.

Conclusion

- Design and implement RT-WLAN:
  - A new Linux device driver with real-time extensions.
  - It is compatible with the Agere ORiNOCO silver cards available in the market.
- Key features:
  - Serve real-time traffic in the high-priority RT queue with EDF policy.
  - Serve non-real-time traffic in the low-priority NRT queue with FIFO policy and adaptive traffic smoothing.

Future Work

- Enhancing the adaptive traffic smoother
  - The current version results in (unnecessary) conservative transmission attempts of NRT packets.
- Service differentiation among NRT traffic
  - Adding multiple NRT queues, and each NRT queue is followed by a different traffic smoother.