RVS Seminar
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MaxMAC: a Maximally Traffic-Adaptive MAC Protocol for Wireless Sensor Networks

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Energy Efficient Medium Access (E^2-MAC) Protocols

- Energy consumption *the* constraining factor in many wireless networks consisting in battery operated devices, especially in WSNs

- Radio Interface (wireless transceiver) is the major source of energy consumption (in WSNs often >95 %)

- Since ~2002, mechanisms and protocols have evolved that allow to communicate at lower energy cost.

- Energy-Efficient MAC Protocol attempt to minimize the sources of energy waste on the MAC layer

Energy Efficient Medium Access (E^2-MAC) Protocols

Try to avoid the sources of energy waste ... [Ye et. al, 2001]

- **idle listening** (keeping the transceiver constantly in the RECEIVE state although nothing is sent nor received)

- **collisions** (unrecoverable frames -> retransmissions -> wasted resources at sender and receiver)

- **overhearing** (receiving unnecessary frames of neighboring nodes)

- **protocol overhead** (expensive control message overhead, large headers)

Save energy by efficiently switching between wireless transceiver chip's operation modes (TRANSMIT, RECEIVE, SLEEP)

Energy Efficient MAC (E^2-MAC) Protocols for Wireless Sensor Networks

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- Typically trade off quality-of-service parameters (throughput, latency) versus higher energy-efficiency

- In the last 5 years, researchers have focused almost uniquely on the energy aspect.

- E^2-MAC protocols often severely restrict throughput and latency

- Typically very static mechanisms – e.g. duty cycling with fixed intervals and static parameter settings

Towards Traffic Adaptivity in Energy Efficient MAC Protocols for WSNs

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- There are many sensor network applications for WSNs where an adaptive behavior on the MAC Layer would be very beneficial.

- **Traffic Adaptivity:** *the ability of the protocol to dynamically react to changing traffic requirements with (de)allocation of resources needed to handle imposed traffic*

Application Scenarios:

- Event-based Applications (Wireless Healthcare Systems monitoring vital signs of Patients, Volcano Monitoring)
- Wireless Multimedia Sensor Networks (WMSNs)

Towards Traffic Adaptivity in Energy Efficient MAC Protocols for WSNs

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Traffic-Adaptivity in Wireless Sensor Networks (SNF Project, Oct. 2009)

Goals:

Develop E^2-MAC protocol mechanisms that dynamically adapt to changing traffic and traffic requirements by using the radio transceiver (and thus, its energy resources) truly in an on-demand manner.

Develop a Metric to quantify Traffic Adaptivity and compare with existing E^2-MAC protocols.

[...]

MaxMAC: a Maximally Traffic-Adaptive MAC Protocol for Wireless Sensor Networks

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MaxMAC Features:

- **Low** power consumption with **low** traffic as with existing E^2-MAC protocols

- Can **maximally adapt** to varying traffic load at run-time

- Exhibits a **high** power consumption in periods of **high** traffic and achieves the same throughput as energy-unconstrained CSMA

MaxMAC: a Maximally Traffic-Adaptive MAC Protocol for Wireless Sensor Networks

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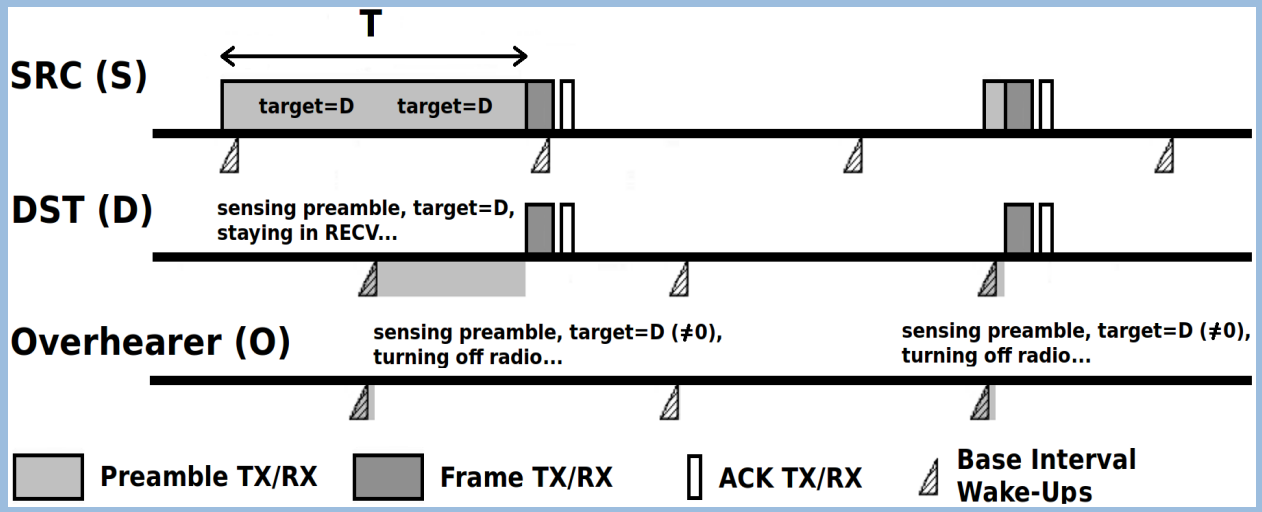
MaxMAC Design:

- **Basic Media Access Mechanism:** MaxMAC combines established design principles of recent research on E^2-MAC protocols:
  Preamble sampling (B-MAC) with preamble minimization (WiseMAC)
  Overhearing Avoidance using target id address within preambles (X-MAC)



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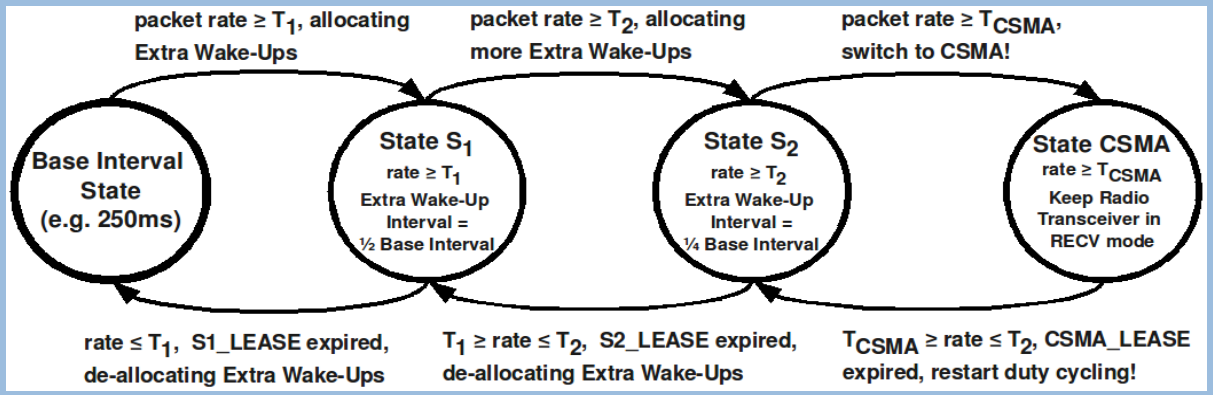
MaxMAC Design:

States and Thresholds: MaxMAC nodes change their state and operate differently in different states in order to support varying load levels

Thresholds = { T1, T2, TCSMA }
States = { Base Interval State, S1, S2, CSMA }



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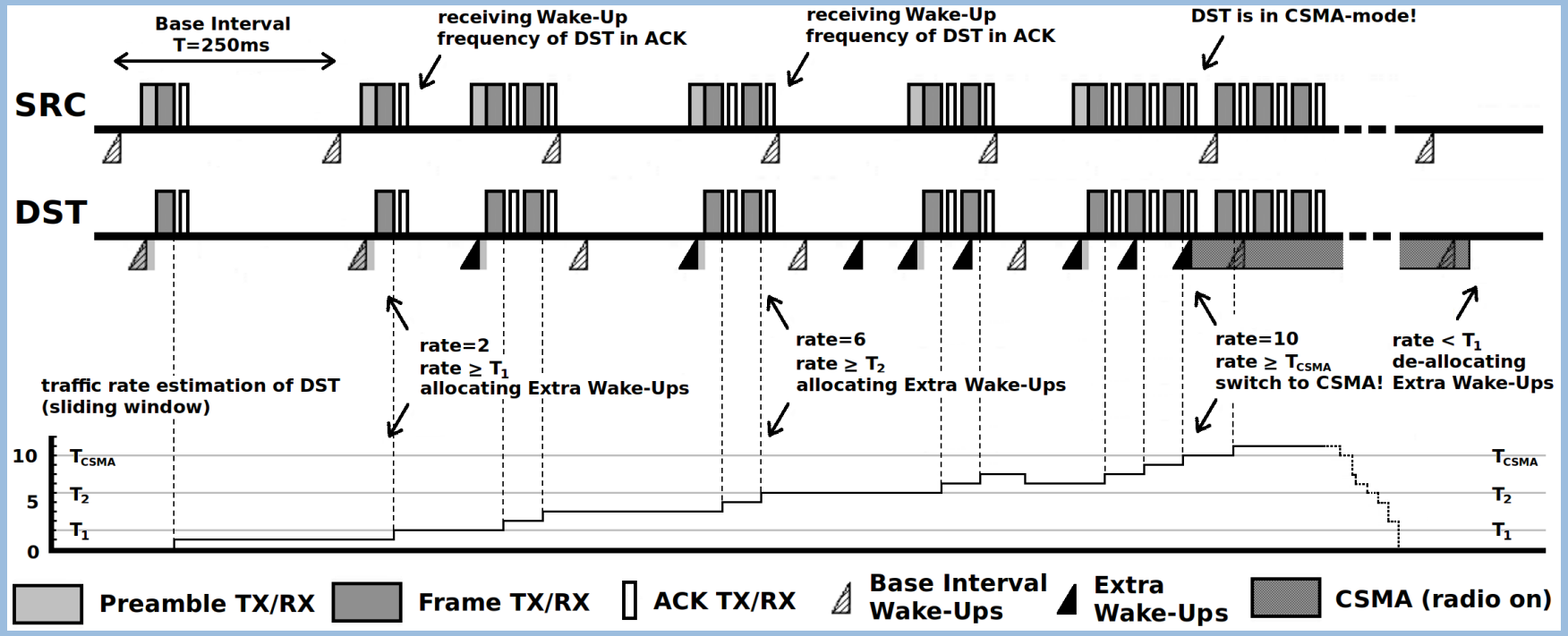


Evaluation of MaxMAC

- Implemented a selection of the most well-known and most-frequently cited E^2-MAC protocols (within simplifications) in OMNET++/MF:

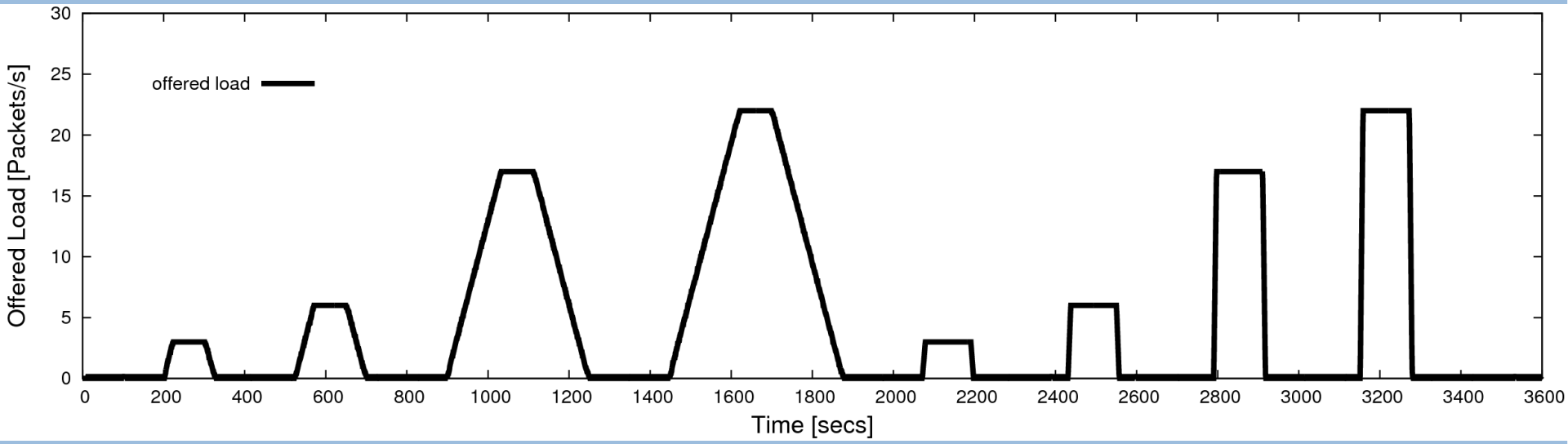
- S-MAC
- T-MAC
- B-MAC
- WiseMAC
- X-MAC

- Further Reference-Protocols:

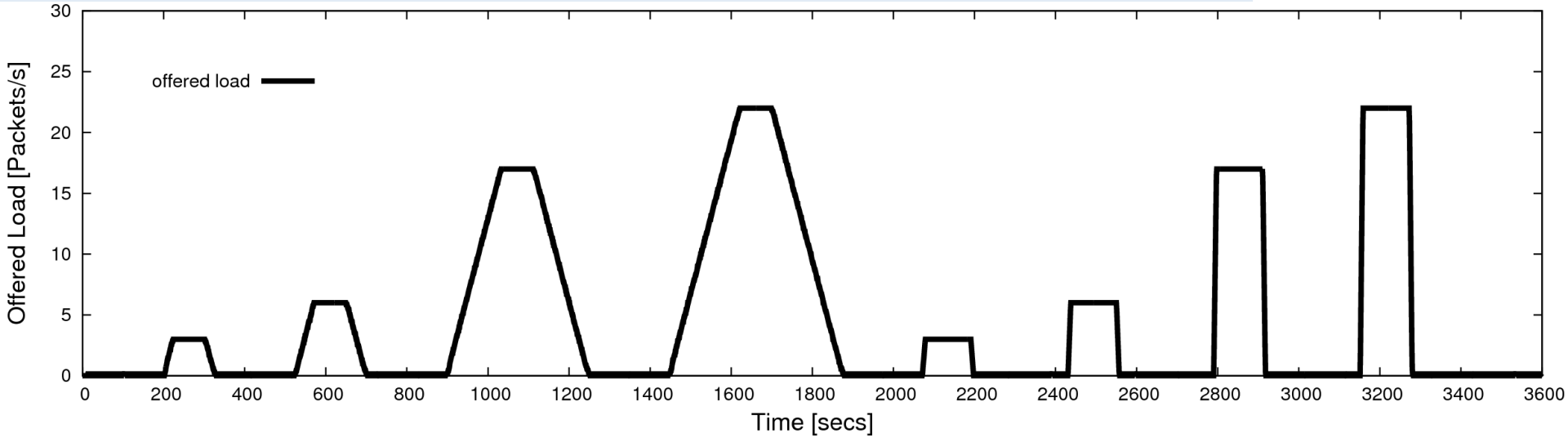
- CSMA
- IdealMAC

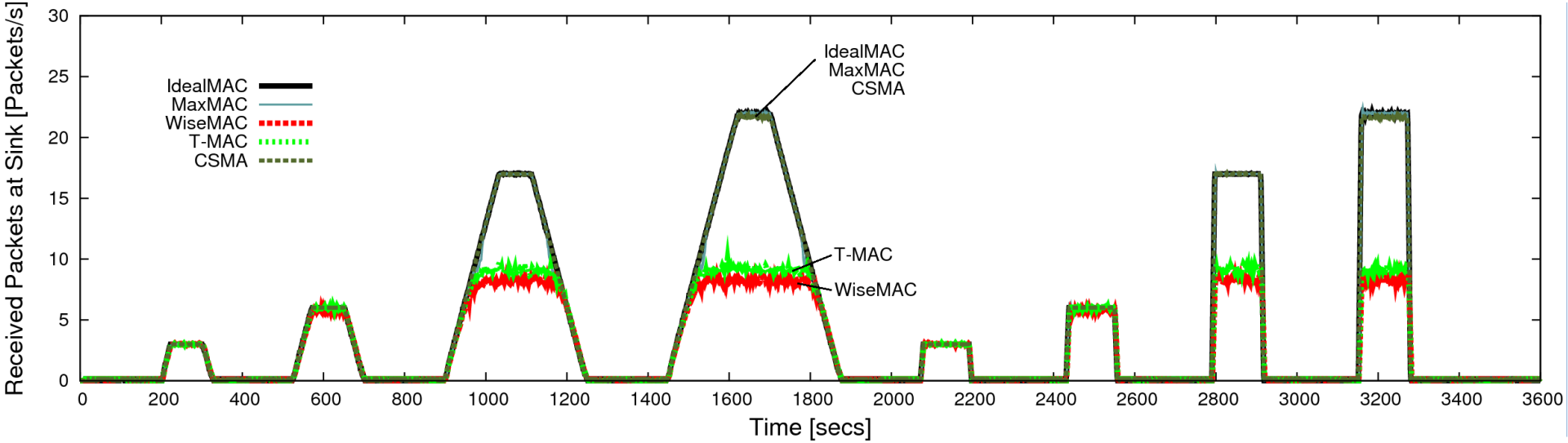
Evaluation of MaxMAC

- sending packets along a 8 nodes chain (generated by SRC node sent towards DST)
- radio transceiver model (rx/tx/sleep) with specs from CC1020 transceiver
- varying traffic load between r=0.1, r=22 packets/sec

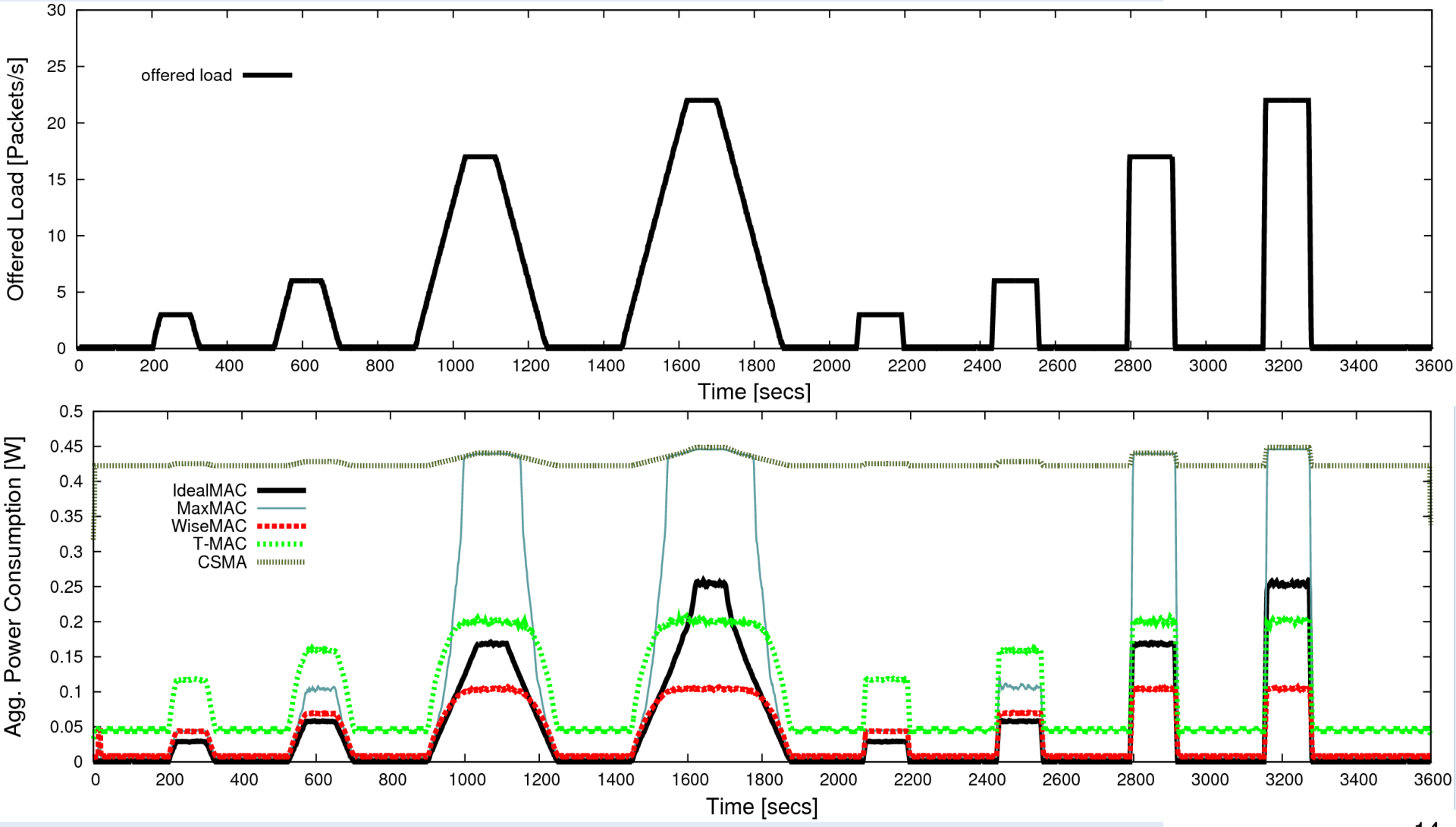


MaxMAC Throughput

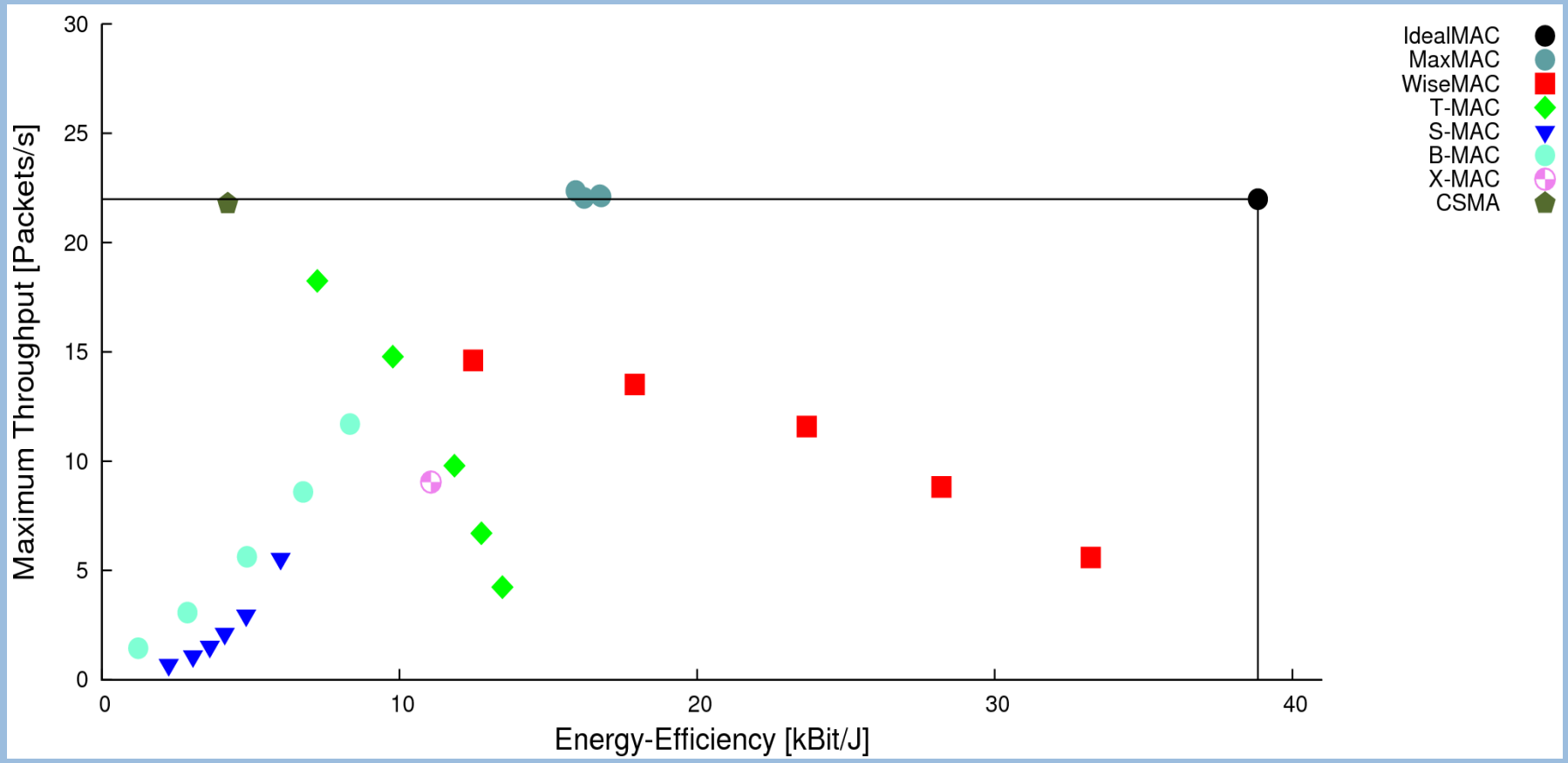




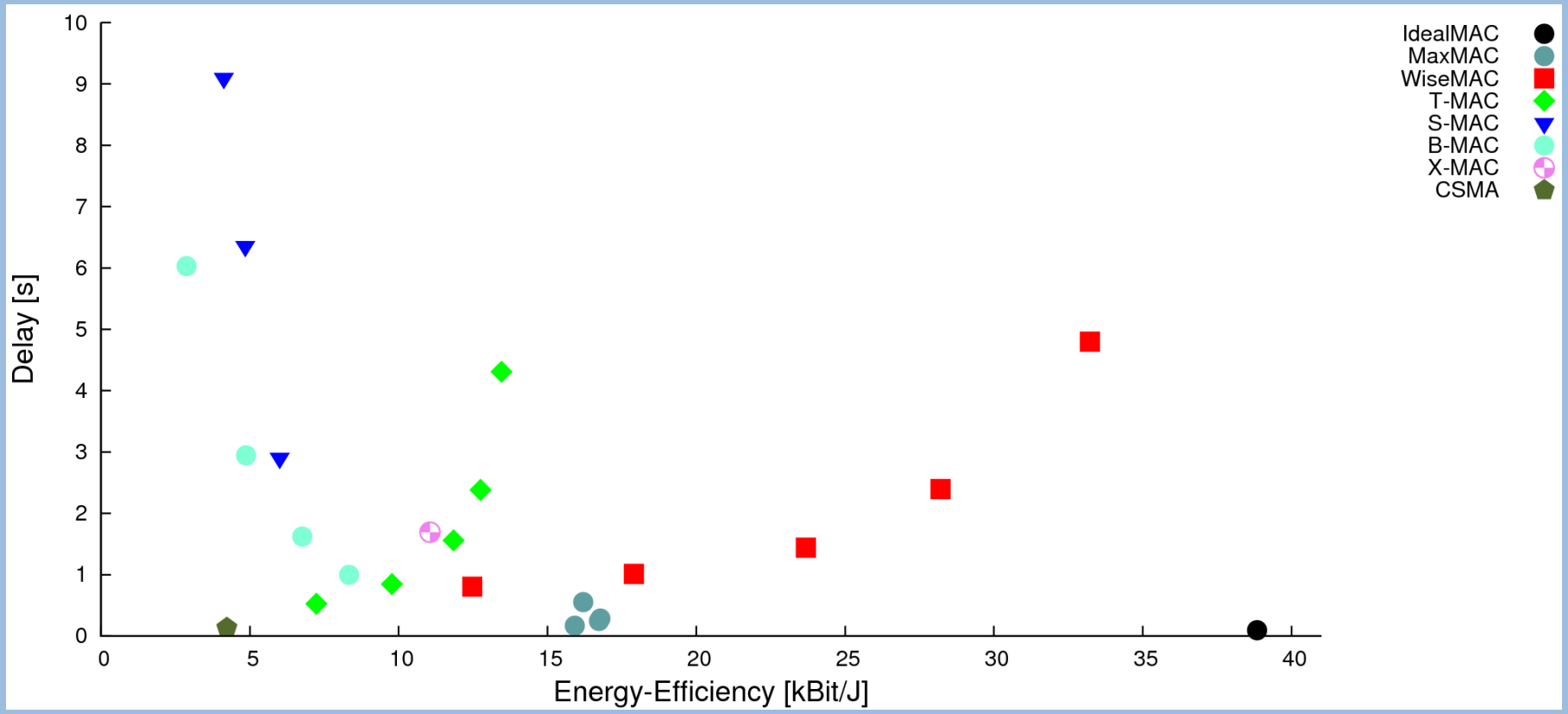
MaxMAC Power Consumption



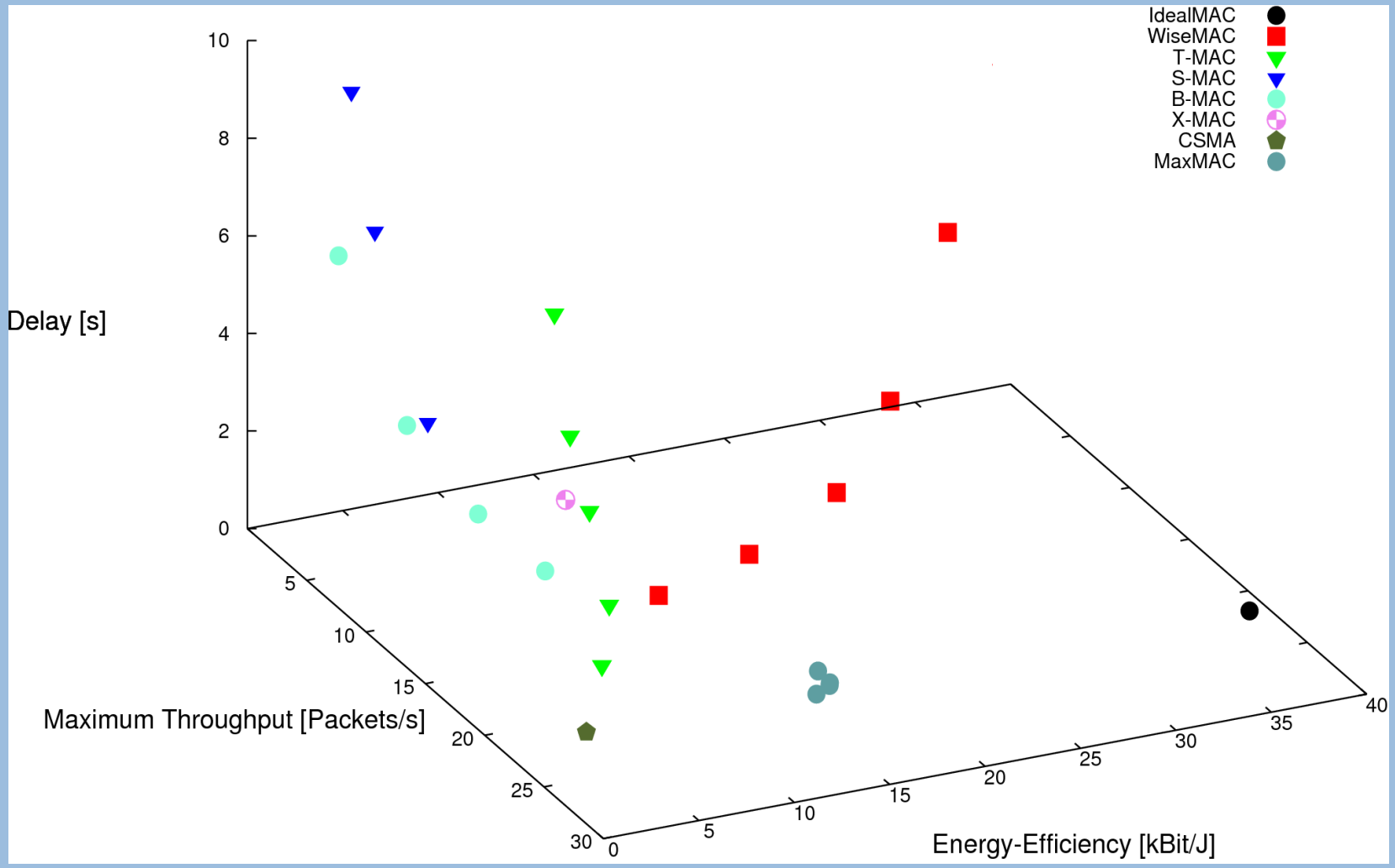
Throughput vs. Energy-Efficiency Tradeoff



Delay vs. Energy-Efficiency Tradeoff



Energy-Efficiency (x) vs. Max. Throughput (y) vs. Delay (z)



Tri-Partite Metric for Traffic Adaptivity

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- Measuring the “Traffic Adaptivity”: Compare the QoS Characteristics Throughput, Delay, Energy-Efficiency of the E^2-MAC Protocol configurations (P_i) with that of IdealMAC (Id)

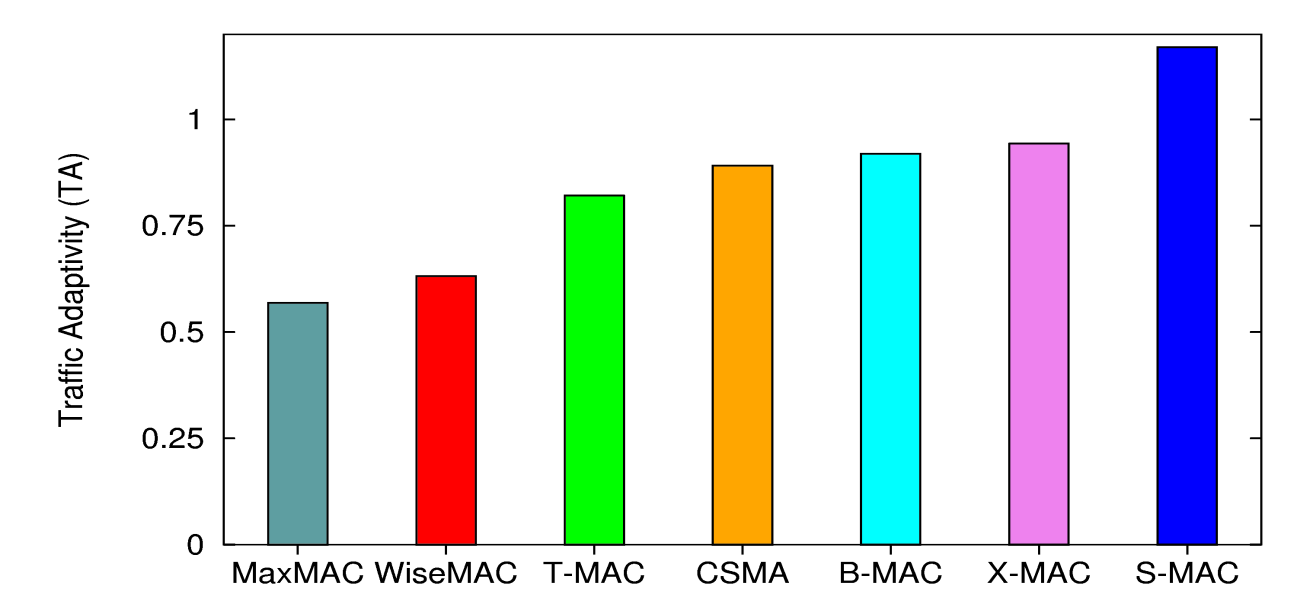
- Normalize axis scaling to values between [0,1]

$$d_{norm}(P_i, Id) = \sqrt{\left(\frac{x_{p_i} - x_{Id}}{x_{Id}}\right)^2 + \left(\frac{y_{p_i} - y_{Id}}{y_{Id}}\right)^2 + \left(\frac{z_{p_i} - z_{Id}}{z_{max} - z_{Id}}\right)^2}$$

- Traffic Adaptivity Metric TA(P) calculates the **best** measured protocol configuration (P_i) for each E^2-MAC Protocol

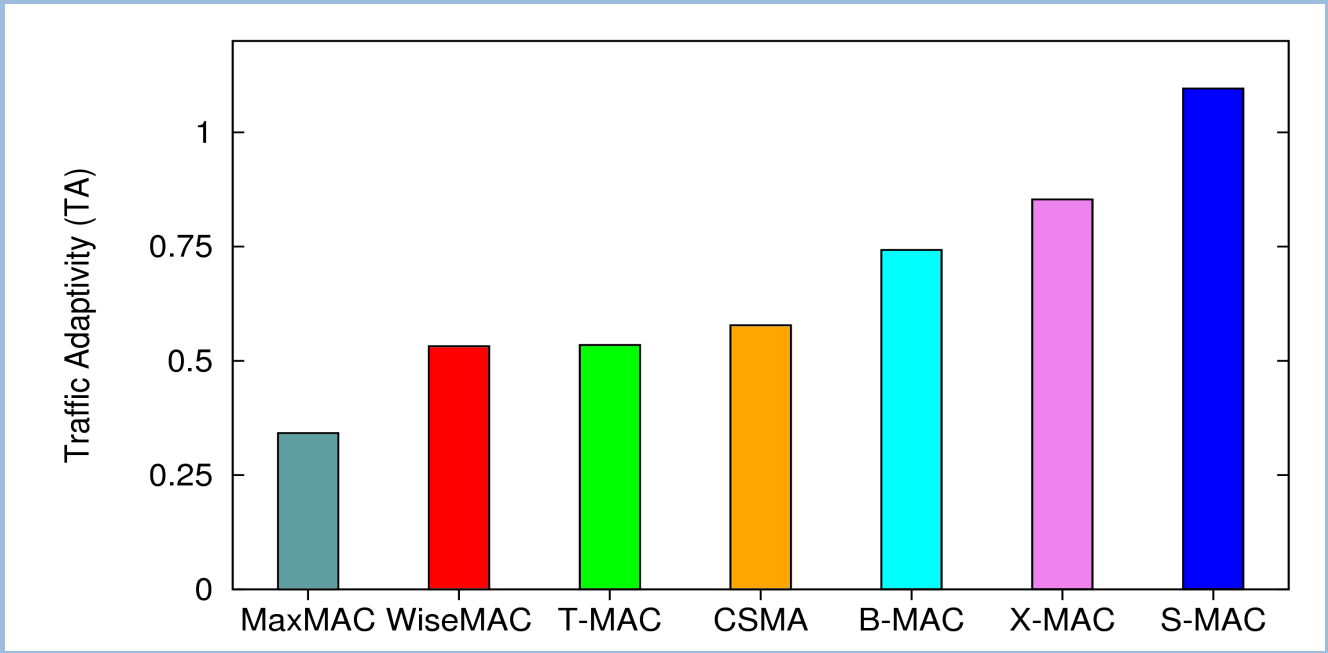
$$TA(P) = \min d_{norm}(P_i, Id) \quad (P_i \in P)$$

Tri-Partite Metric for Traffic Adaptivity



- Applying TA-Metric to the simulated E^2-MAC protocols
- Given that Efficiency, Throughput and Latency are equally important, MaxMAC performs >10% better than the next better protocol (WiseMAC)

Tri-Partite Metric for Traffic Adaptivity



- Given that Throughput and Latency are twice as important as Energy-Efficiency, MaxMAC performs 40% better than the next better protocol (WiseMAC)

Conclusions

- MaxMAC: E^2-MAC protocol targeting at **maximal run-time Traffic Adaptivity**

- MaxMAC has a **low energy footprint** in **low traffic** phases but can reach the **high throughput** of energy-unconstrained CSMA in high traffic phases

- MaxMAC combines advantages of low-power E^2-MAC protocols (high efficiency) with that of energy-unconstrained CSMA (high throughput)

Outlook

- Refine MaxMAC mechanisms to trigger state-changes (e.g. over multiple hops)

- Self-parametrization and learning of threshold values

- Real-World Implementation on the MSB430

- Evaluation in small-scale test-scenarios

Thanks for your attention!

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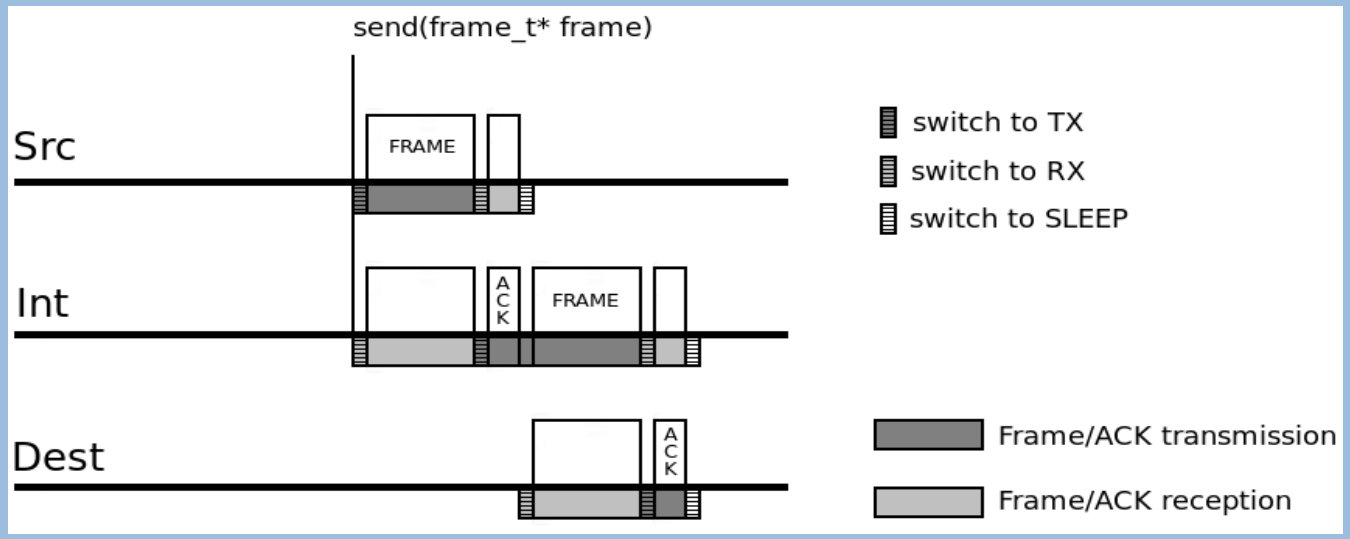
Questions ?

IdealMAC Reference Protocol for “lower bounds”

- IdealMAC models the physical contraints (channel limitation, transceiver switches)
- “Information Asymmetry” - the biggest challenge of all E2-MAC protocols - between sender and receiver is disregarded
- Node X “knows” when Node Y intends to send a message destined to it



- IdealMAC is a reference protocol! It illustrates the theoretic limits of E2-MAC protocols...