A Hybrid MAC with Intelligent Sleep Scheduling for Wireless Sensor Networks

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Outline of Presentation

- Introduction
- Standardization of MAC protocol for Sensor Network
- Proposed MAC protocol
- Result & Discussion
- Summary

Introduction

- Wireless sensor networks (WSNs) have become very popular in recent years.
- The sensor nodes are typically
  - small,
  - low-cost, and
  - equipped with **low-powered battery**
- **Prolonging lifetime** of sensor nodes is definitely a critical issue.
- Therefore, in order to design a MAC protocol for WSNs it is important to consider **energy efficiency.** The other important attributes are **latency, delivery ratio, fairness** etc.

Introduction

- **Idle listening** is the major source of energy wastage for WSNs.
- Therefore, **nodes** do not wake-up all the time to maximize throughput and minimize delay
- Rather nodes **prefer energy preservation by going to sleep from time to time**.
- So, a straightforward approach can be to **assign each communication link a time slot.**
- But this scheme requires much **more time slots** than **necessary**.

Introduction

- Minimizing the number of slots assignment for an **interference free link scheduling is a NP complete** problem .
- **Broadcast** scheduling is less energy efficient.
- Henceforth**, we propose** a new hybrid MAC protocol for wireless sensor network, called **IH-MAC(Intelligent Hybrid MAC), which combines –**
  - **the strength of CSMA,**
  - **pair wise TDMA (link scheduling)**
  - **broadcast TDMA.**

Standardization

- The first step of **standardization** for low rate wireless personal area networks was taken in 2003 when **IEEE 802.15.4** was approved.
- IEEE 802.15.4 standard specifies only the lowest part of OSI communication model: PHY layer and MAC sub-layer.
- But **unlike 802.11 WLAN** cards where MAC is usually included as part of the chipset**,**
- In **WSNs** the **MAC designer** has **absolute control on the design of MAC layer.**

Standardization

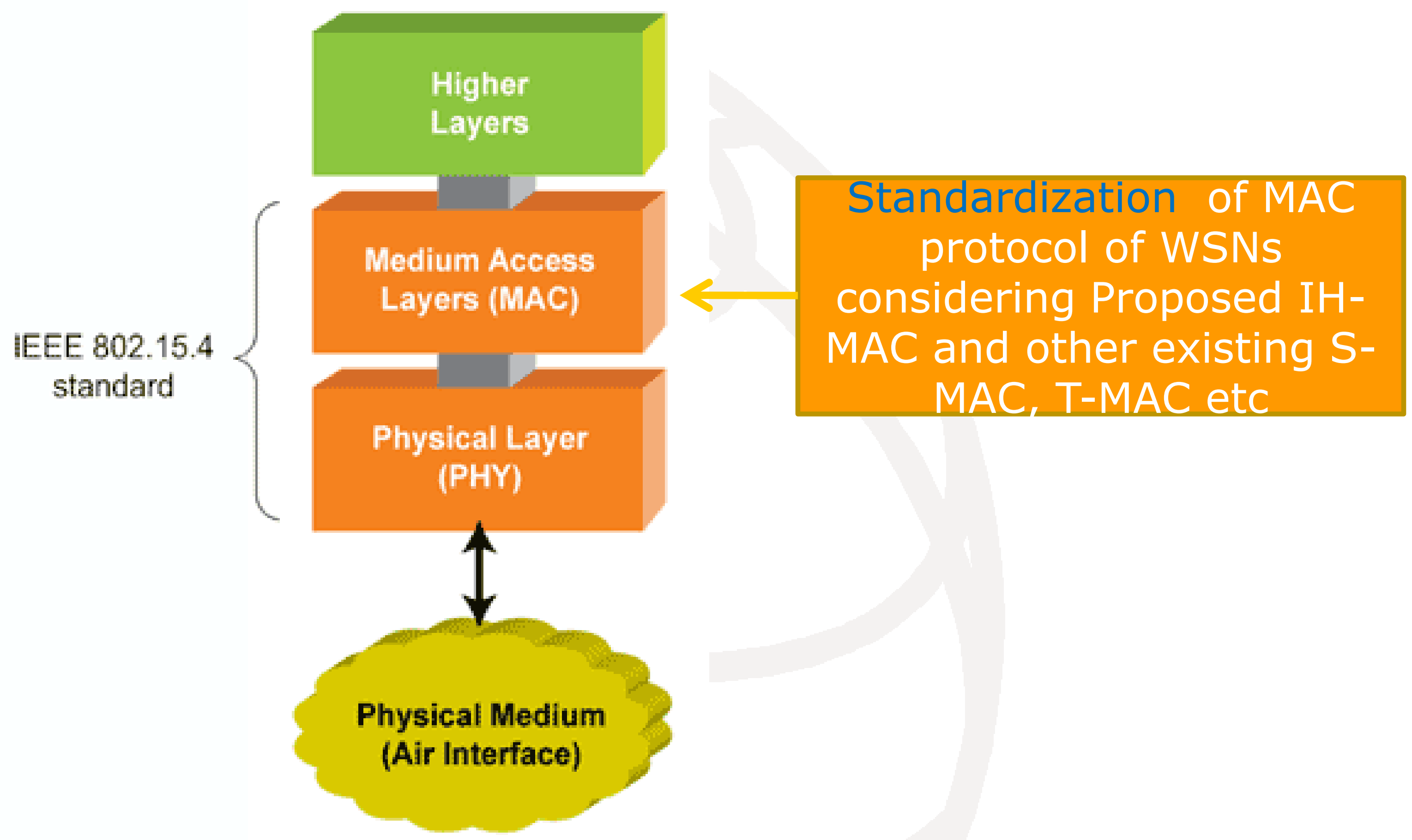

Fig 1. Structure of IEEE 802.15.4 protocol stack and the area of our proposed work

Proposed MAC Protocol

- Each slot in IH-MAC is a periodic interval which consists of
  - **fixed length SYNC period,**
  - **fixed length Listen period (For RTS/CTS)**
  - **sleep period.**
- Nodes are allowed to transmit in any slot, but **owner** of the slot will get the **priority.**
- **Contention window size** ensures priority.
- Each node can make some of its owned slot as a ***rendezvous slot*.**
- A ***rendezvous slot*** is a slot explicitly dedicated to a pair of nodes to communicate .

Proposed MAC Protocol

- **Owner calculation** is performed by each sensor node **locally** by **clock arithmetic**.
- Let there are 8 neighbor nodes (every node is 1 or 2-hop neighbor to each other),
- T1, T2…represent the slot sequences and S1, S2…represent the sensor nodes.
- According to clock arithmetic (mod 8) sensor node **S1** will be the **owner** of **slot T1 & T9.**

S1	S2	S3	S4	S5	S6	S7	S8	S1	S2
T1	T2	T3	T4	T5	T6	T7	T8	T9	T10

Fig.2 Owner selection of each slot for 8 sensor nodes

Proposed MAC Protocol

- The rendezvous slots can also be calculated by clock arithmetic,
- Let node **S1 wants** to create a rendezvous.
- By using **modulo 16**, the rendezvous slots of node S1 will be a subset of [1, 17…].
- **S1** can make **T17** as its **rendezvous slot.**
- Though **S1 is owner** of both **T9 and T17** but S1 cannot make T9 as its rendezvous slot. It is because 9 is not a subset of [1, 17 ….].

S1	S2	S3	S4	S5	S6	S7	S8	S1	S2
T9	T10	T11	T12	T13	T14	T15	T16	T17	T18

Fig.3 Rendezvous slot selection for 8 sensor nodes (T17 is rendezvous slot for S1 but T9 is not rendezvous slot)

Proposed MAC Protocol

- Consider a simple case of four sensor nodes A, B, C,& D. And there are four consecutive slots.
- During Slot i, Let data **transmission** occur between node **B and C**.
- But **A and D** also
  - need to **wake up**
  - Subsequently they go to **sleep**

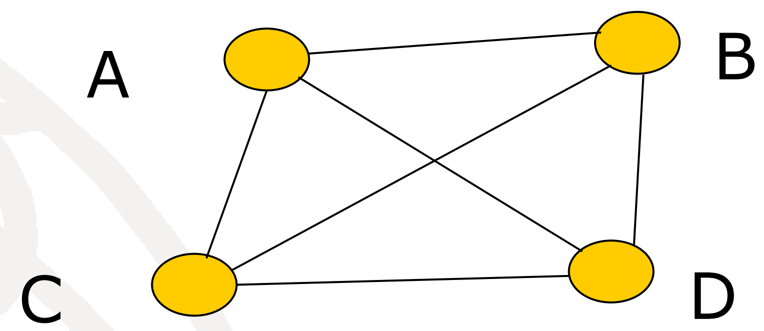

Fig 4. Network of 4 Sensor Nodes connected to each other

	Slot i		Slot i+1		Slot i+2		Slot i+3	
Node A	Listen	Sleep	Listen	Sleep	Listen	DATA	Listen	Sleep
Node B	Listen	DATA	Listen	DATA	Sleep		Listen	Sleep
Node C	Listen	DATA	Listen	Sleep	Listen	DATA	Listen	Sleep
Node D	Listen	Sleep	Listen	DATA	Sleep		Listen	Sleep

Fig.5. Timing Diagram of sensor nodes working in IH-MAC (The blue portion of figure is rendezvous slot of IH-MAC and the remaining slots are like S-MAC, T-MAC etc.)

Proposed MAC Protocol

- In slot i+2, **node A and C created rendezvous** between them.
- On that slot node **B and D** will not wake up.
- Thus, **B and D save energy** by
  - **lingering sleep time**
  - **avoiding transition**

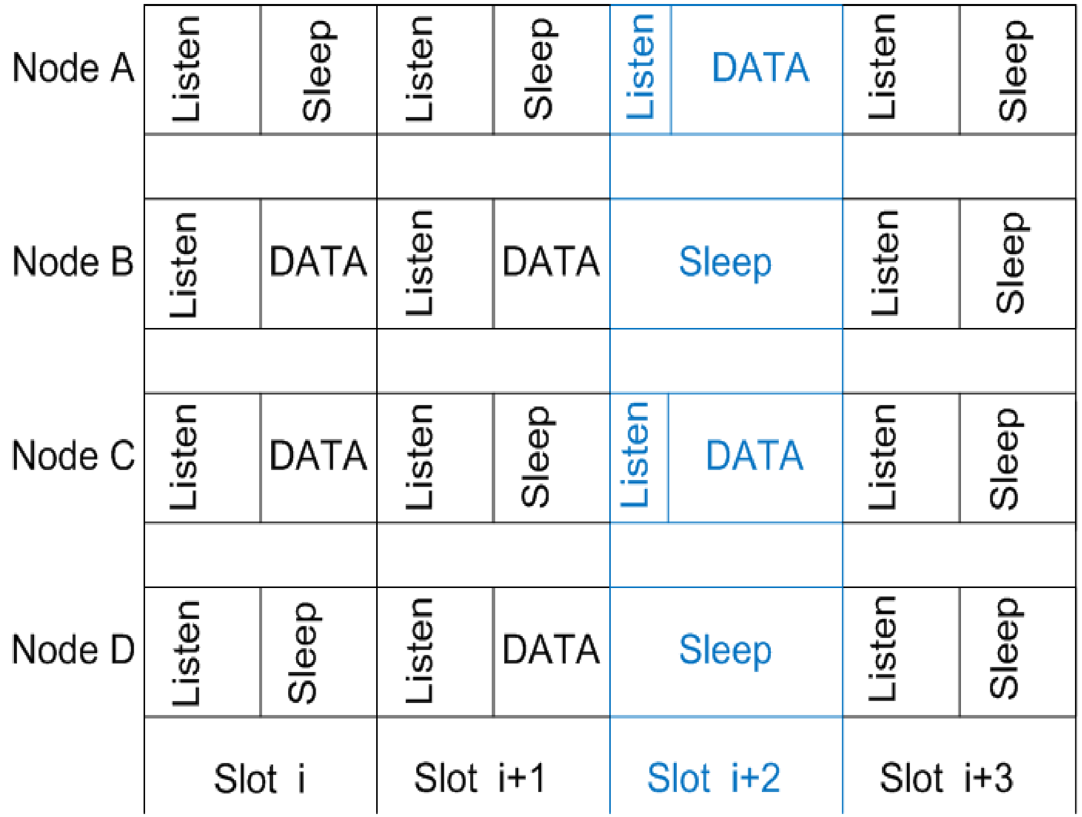

Fig.5. Timing Diagram of sensor nodes working in IH-MAC (The blue portion of figure is rendezvous slot of IH-MAC and the remaining slots are like S-MAC, T-MAC etc.)

Proposed MAC Protocol

- Node **A** & **C** save energy by avoiding
  - **RTS, CTS**
  - **contention** for getting the slot.
- Thus, creation of **rendezvous** slot **enhance energy efficiency for all nodes** in two hop neighbor whether they participate in transmission or not

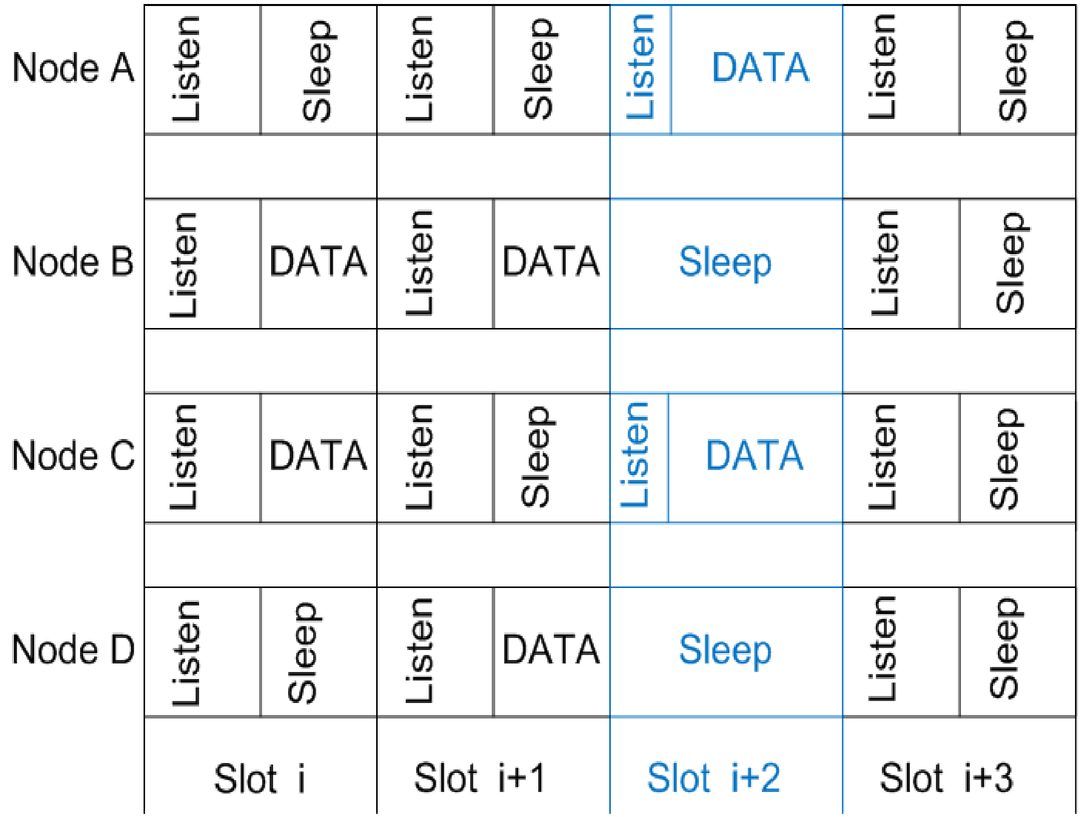

Fig.5. Timing Diagram of sensor nodes working in IH-MAC (The blue portion of figure is rendezvous slot of IH-MAC and the remaining slots are like S-MAC, T-MAC etc.)

Proposed MAC Protocol

- The **power adjustment features** of IH-MAC allow the sensor nodes to suitably vary the transmission power to reduce energy consumption.

$$P_{desired} \approx \frac{P_{\max}}{P_r} \times Rx_{thres} \times c$$

- Here, Rx_{thres} is the minimum necessary signal strength, P_r is the received power level and c is a constant . And sensor node transmits the **RTS** and **CTS** packets with **maximum power** $P_{\max}$
- The source node uses power level $P_{desired}$ to transmit data packet.

Proposed MAC Protocol

- We also develop an **analytical model** for the energy consumption of nodes for IH-MAC. For time constraints we will omit the detail.
- **Simulation time**,

$$t_{SIM} \approx t_{TX} + t_{RX} + t_{OH} + t_{IDLE} + t_{SLEEP} + t_{TRANS}$$

- t_{TX}, t_{RX}, t_{OH}, t_{IDLE}, t_{SLEEP}, t_{TRANS} ,are denoted as the time spent for transmitting, receiving, overhearing, idle listening, sleep, and radio transitions during sleep to wakeup state of a sensor node, respectively.

Proposed MAC Protocol

- **Energy consumption during t_{SIM}**

$$e \approx n_{TX(w)} \times e_{TX(w)} + n_{TX(R)} \times e_{TX(R)} + n_{RX(w)} \times e_{RX(w)}$$
$$+ n_{RX(R)} \times e_{RX(R)} + t_{OH} \times e_{OH} + t_{IDLE} \times e_{IDLE}$$
$$+ t_{SLEEP} \times e_{SLEEP} + t_{TRANS} \times e_{TRANS}$$

- $n_{TX(w)}$, $n_{TX(R)}$, $n_{RX(w)}$, $n_{RX(R)}$ represents the total number of times that a node transmits or receives with or without rendezvous during t_{SIM}
- And e_X represents the required energy for the operation x

Simulation Parameter

- The parameter we use in performance evaluation:

Parameter	Value
Channel Bandwidth	20 kbps
Data Packet length	20 bytes
Transmission power	36 mW
Receive power	14.4 mW
Idle power	14.4 mW
Sleep state	15 µW
Frame Length	1 sec
Threshold value for the buffer size (for IH-MAC)	3 packet
Duty cycle	15 %

Result & Discussion

- We took existing S-MAC (Sensor MAC) and T-MAC (Time out MAC) protocol for comparison.
- Performance metrics used in evaluation of IH-MAC protocol are
  - **Energy consumption,**
  - **Delivery ratio and**
  - **Average Packet Latency**.
- **Energy Consumption:** During heavy traffic IH-MAC outperforms S-MAC and performs like T-MAC. It is because **during heavy traffic IH-MAC makes rendezvous slots.**

Result & Discussion

- But as traffic declines energy efficiency of IH-MAC deteriorates.
- T-MAC perform better during low traffic. **But, T-MAC trades off latency for energy savings.**
- It is evident from that If we can implement **power adjustment feature of IH-MAC** it will be more energy efficient.

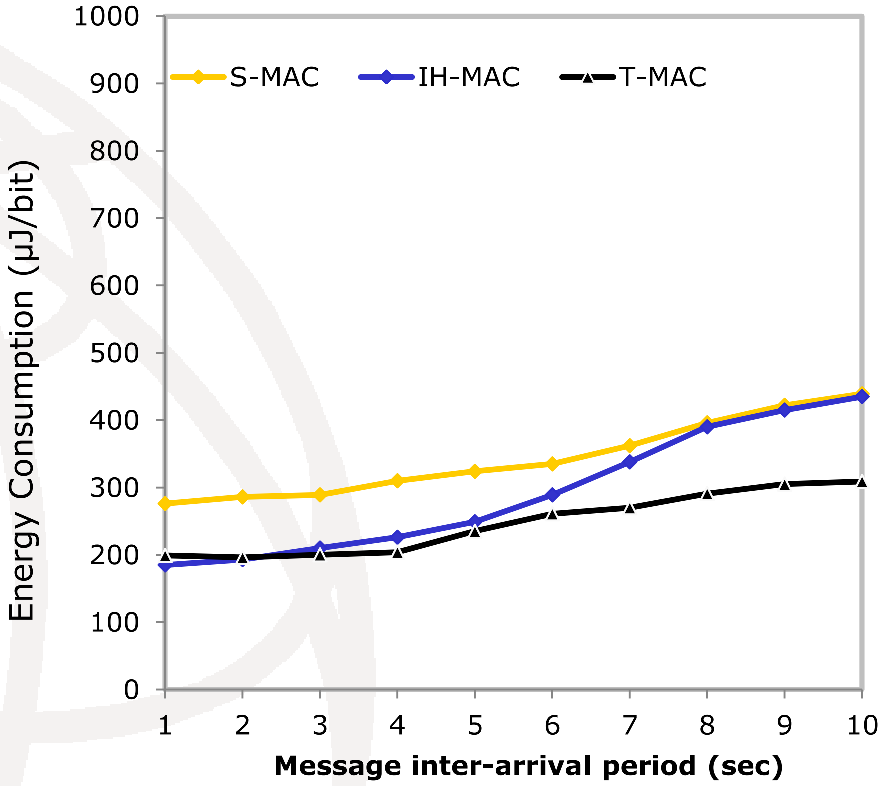

Fig. 6(a) Average energy consumption per bit under different traffic load

Result & Discussion

- **Average packet latency:**
- The IH-MAC protocol achieves better delay performance.
- It is because during heavy traffic load IH-MAC use the **link scheduling** where it **minimizes**
  - **control signal**
  - **contention** phase.

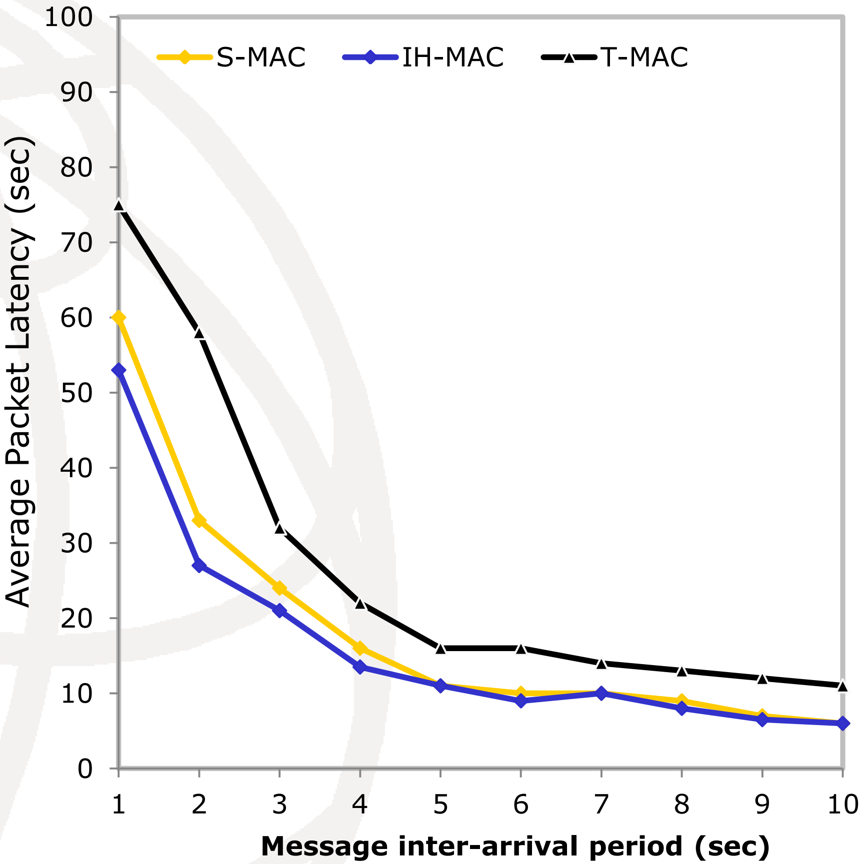

Fig. 6(b) Packet latency under different traffic load

Result & Discussion

- **Average Packet Delivery Ratio**:
- The average packet delivery ratio is the number of packet received to the number of packets sent over all the nodes.
- **Delivery ratio of IH-MAC is higher** due to use of link scheduling which is like TDMA.

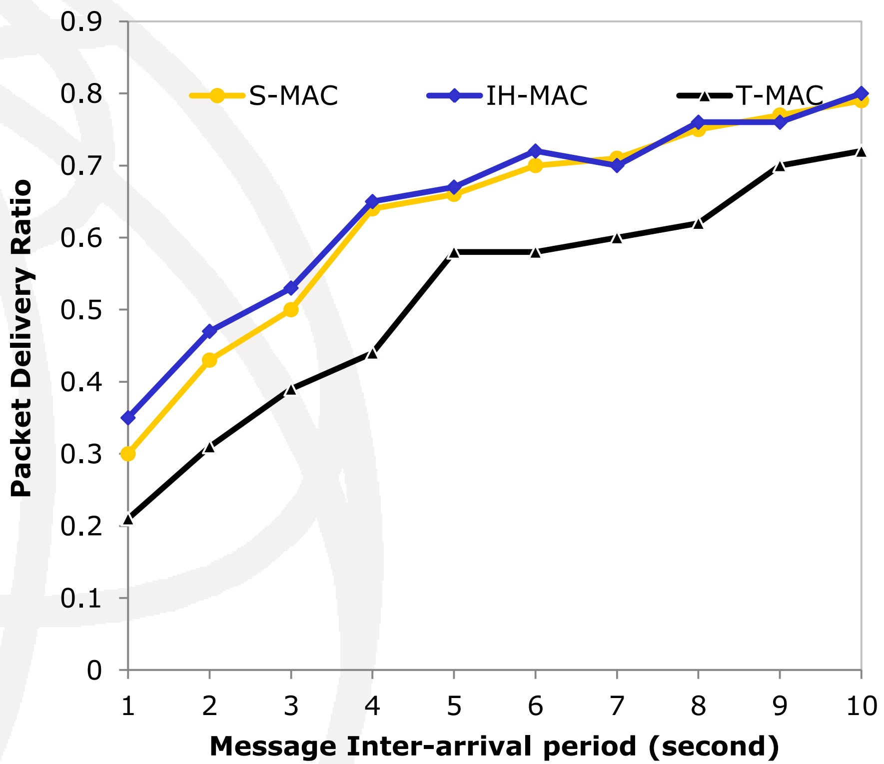

Fig. 6(c) Packet delivery ratio under different traffic load

Summary

The contribution of the paper are:

- **Identification of need for standardization** work in the area of **MAC protocol of WSNs.**
- **Proposal** of a **novel MAC protocol** which can be consider as a candidate for standardization.
- **Introducing** the concept of **link scheduling and broadcast scheduling together**.
- **Introducing power adjustment feature** for the sensor nodes during transmission.
- As a future work, we intend to implement the power adjustment feature of IH-MAC and also we have a plan to implement our protocol on the Mote hardware.

- Thank You