An Energy-Efficient MAC Protocol for Wireless Sensor Networks

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Outline

- Introduction
- Protocol description and discussion
  - Basic parameter design
  - Phase switch schedule
  - Time-slot assignment
- Simulations
- Conclusions

Introduction

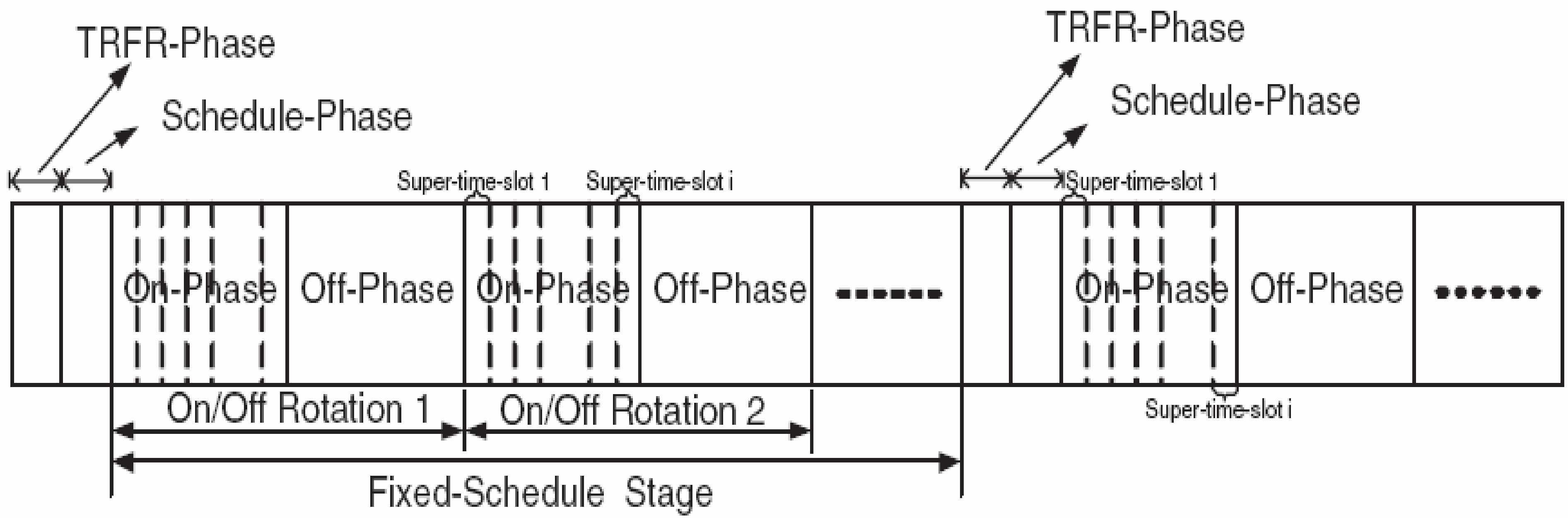
- Most energy-efficient MAC protocols assume perfect network time synchronization
  - Clock drifts exist
- The duration of power on/off is seldom discussed
- Traffic arrival rate for different nodes at different time is fluctuating

Goals of This Paper

- The authors propose an energy-efficient MAC protocol
  - Remove tight dependency on time synchronization
  - Apply free-running method and fuzzy logic rescheduling scheme, phase-switching schedules are set up and clock drifts among nodes are compensated.
  - a trafficstrength- and network-density-based model to determine essential algorithm parameters

ASCEMAC
Asynchronous Energy-Efficient MAC Protocol

ASCEMAC Protocol Model



1. **TRFR-Phase**: cluster members transmit message to cluster head
2. **Schedule-Phase**: cluster heads to broadcast phase-switching schedules
3. **On-Phase**: all nodes to power on their radios to make communication
4. **Off-phase**: all nodes to power off their radios

TRFR Message Format

T	SRC	AR_d	SR_d	FR	OR

T	packet type
SRC	source address
AR_d	data arrival rate
SR_d	data service rate
FR	transmission failure rate
OR	buffer overflowing rate

Information for a cluster head to determine the scheduling

Parameter Design

Combine:

$$T_f = \min\left\{(2W_{max} - T_n), \min_i\left(\frac{k_i}{\lambda_i} - T_n\right)\right\}$$

$$T_n = \frac{T_d T_f \sum_{i=1}^{N} \lambda_i}{1 - T_d \sum_{i=1}^{N} \lambda_i}$$

$\phi = \sum_{i=1}^{N} \lambda_i$

T_n: on phase duration

T_f: off-phase duration

T_d: slot time

W_{max}: maximum waiting time

λ_i: traffic arrival rate for node i

K_i: buffer size

Parameter Design

$$1)\,when\quad 2W_{max} < \min_i(\frac{k_i}{\lambda_i}) \qquad 2)\,when\quad 2W_{max} \geq \min_i(\frac{k_i}{\lambda_i})$$

$$\begin{cases} T_f = 2W_{max}(1 - T_d\phi) \\ T_n = 2W_{max}T_d\phi \end{cases} \qquad \begin{cases} T_f = \min_i(\frac{k_i}{\lambda_i})(1 - T_d\phi) \\ T_n = \phi T_d \min_i(\frac{k_i}{\lambda_i}) \end{cases}$$

- The goal of adjusting parameters
  - Extend the power off time to save more energy
  - Adjust the data packet waiting time to an acceptable value

Schedule Message Format

T	SRC	D_{off}	D_{on}
SRC_1	$DEST_1$	D_{df1}	D_{s1}
SRC_2	$DEST_2$	D_{df2}	D_{s2}
- - - - - - - - - - - - -			
SRC_i	$DEST_i$	D_{dfi}	

- T packet type
- SRC source address
- D_{off} off phase duration
- D_{on} on phase duration
- D_{sI} supper time slot duration for node i
- D_{dfi} supper time slot starts defer time
- SRC_1 source address for ith supper time slot
- $DEST_i$ destination address for ith supper time slot

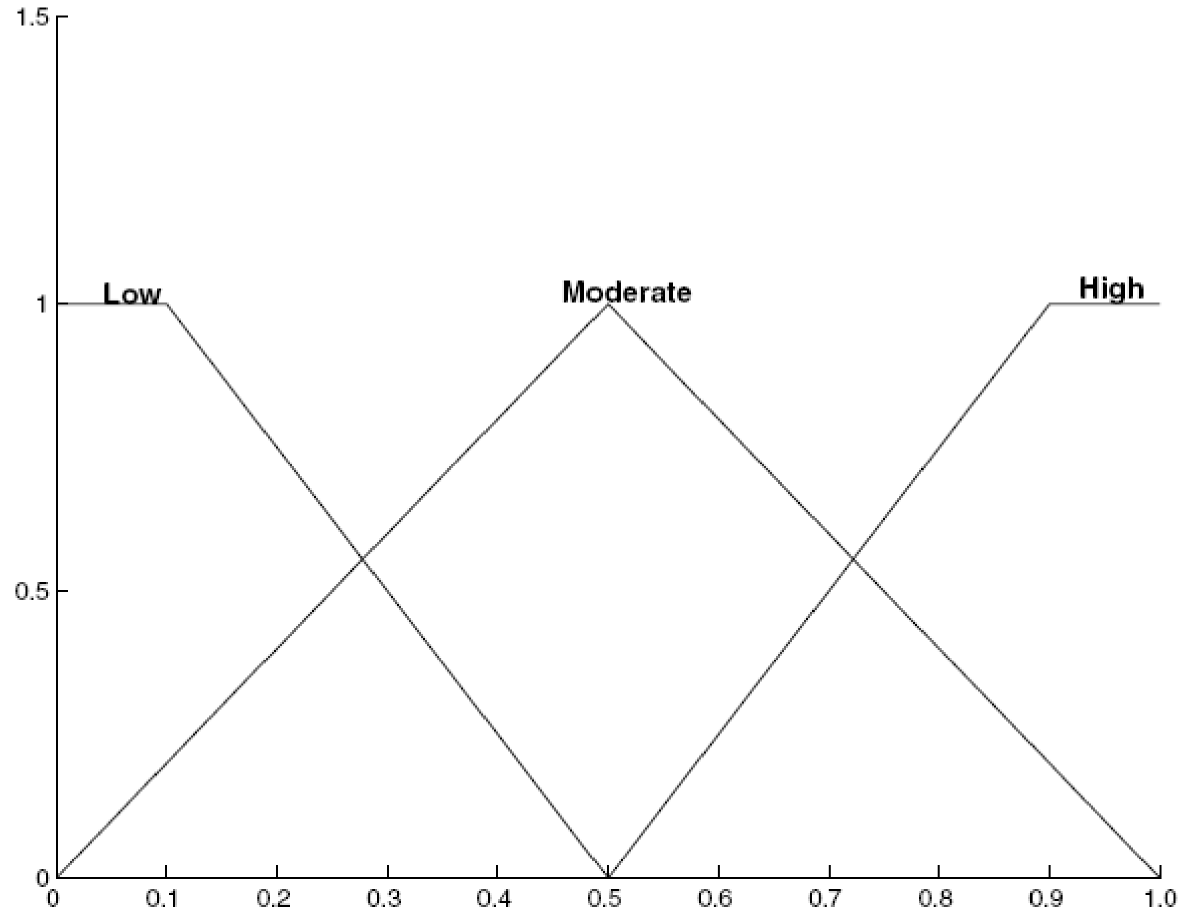
Interval of Schedule Broadcast

$$T_i = \xi_i \times T_{i-1}$$

- ξ_i is the interval adjusting function
- Three parameters are used to design ξ_i
  - Ante1: ratio of nodes with overflowed buffer
  - Ante2: ratio of nodes with high failing transmission rate
  - Ante3: ratio of nodes experiencing unsuccessful transmission

Interval of Schedule Broadcast

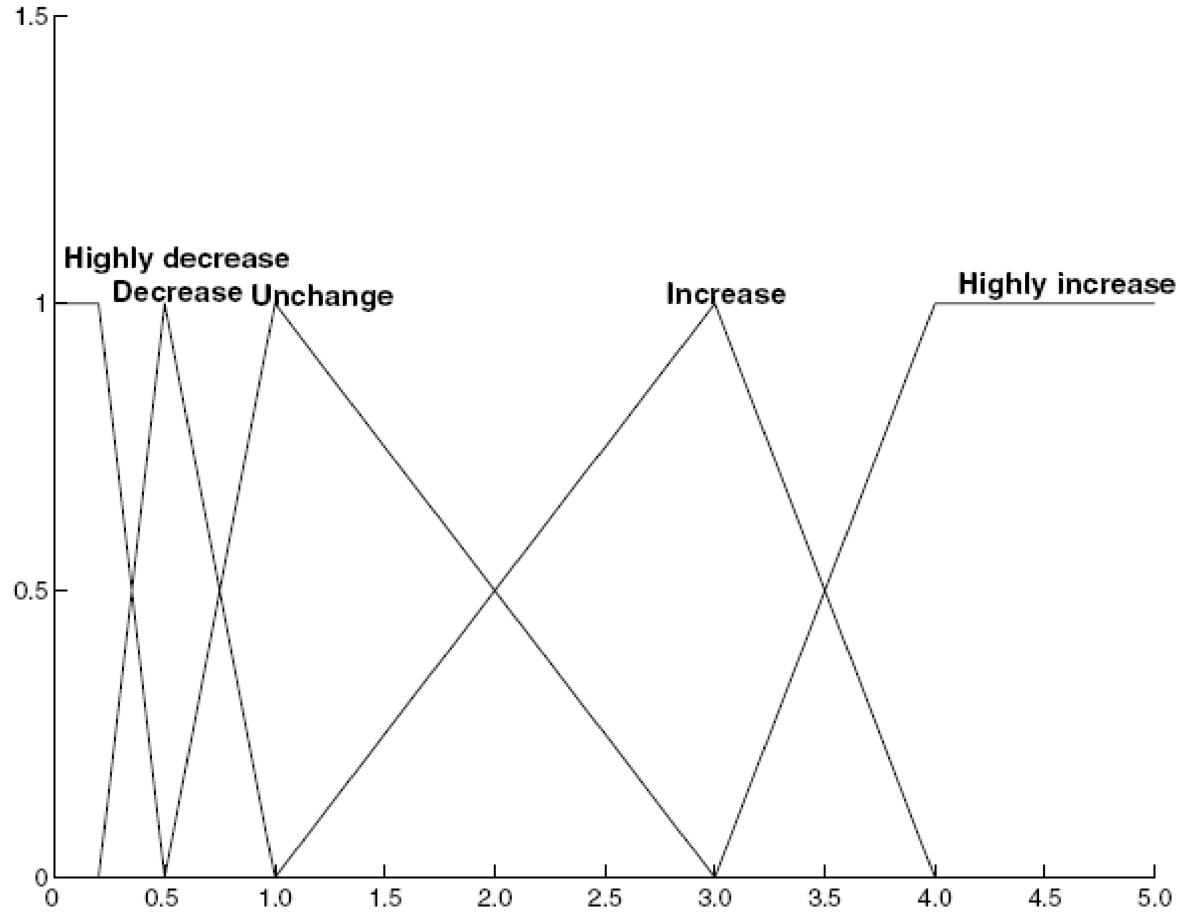
- The linguistic variables used to represent those parameters are divided into three levels: *Low*, Moderate, High



The rules for adjusting the interval of schedule broadcast

Rule	*Ante1*	*Ante2*	*Ante3*	*Consequent*
1	*Low*	*Low*	*Low*	*HighlyIncrease*
2	*Low*	*Low*	*Moderate*	*Increase*
3	*Low*	*Moderate*	*Moderate*	*Decrease*
4	*Low*	*Moderate*	*High*	*Decrease*
5	*Moderate*	*Low*	*Moderate*	*Increase*
6	*Moderate*	*Low*	*High*	*Unchange*
7	*Moderate*	*Moderate*	*Moderate*	*Decrease*
8	*Moderate*	*Moderate*	*High*	*HighlyDecrease*
9	*Low*	*High*	*High*	*Decrease*
10	*Moderate*	*High*	*High*	*HighlyDecrease*
11	*High*	*Low*	*Moderate*	*Increase*
12	*High*	*Low*	*High*	*Unchange*
13	*High*	*Moderate*	*Moderate*	*Decrease*
14	*High*	*Moderate*	*High*	*Decrease*
15	*High*	*High*	*High*	*HighlyDecrease*

Interval of Schedule Broadcast



Using Fuzzy Function

- The authors mention that ξ_i is defuzzified by

$$\xi(x_1, x_2, x_3) = \frac{\sum_{l=1}^{15} \bar{\xi}^l \mu_{\mathrm{F}_1^l}(x_1)\mu_{\mathrm{F}_2^l}(x_2)\mu_{\mathrm{F}_3^l}(x_3)}{\sum_{l=1}^{15} \mu_{\mathrm{F}_1^l}(x_1)\mu_{\mathrm{F}_2^l}(x_2)\mu_{\mathrm{F}_3^l}(x_3)}$$

E. H. Mandani, “Application of fuzzy logic to approximate reasoning using linguistic systems”, *IEEE Trans. On system, Man, and Cybernetics*, vol. 26, no. 12, pp. 1182-1191, 1977.

Time-slot assignment

$\triangle t_1$: time difference between nodes

$T_{s,min}$: the least time needed to detect the synchronization information

1) If $T_{s,min} < \Delta t_1 < T_d$

$\frac{n-1}{n}\%$ Successful transmission rate

2) If $T_d < \Delta t_1 < 2T_d$

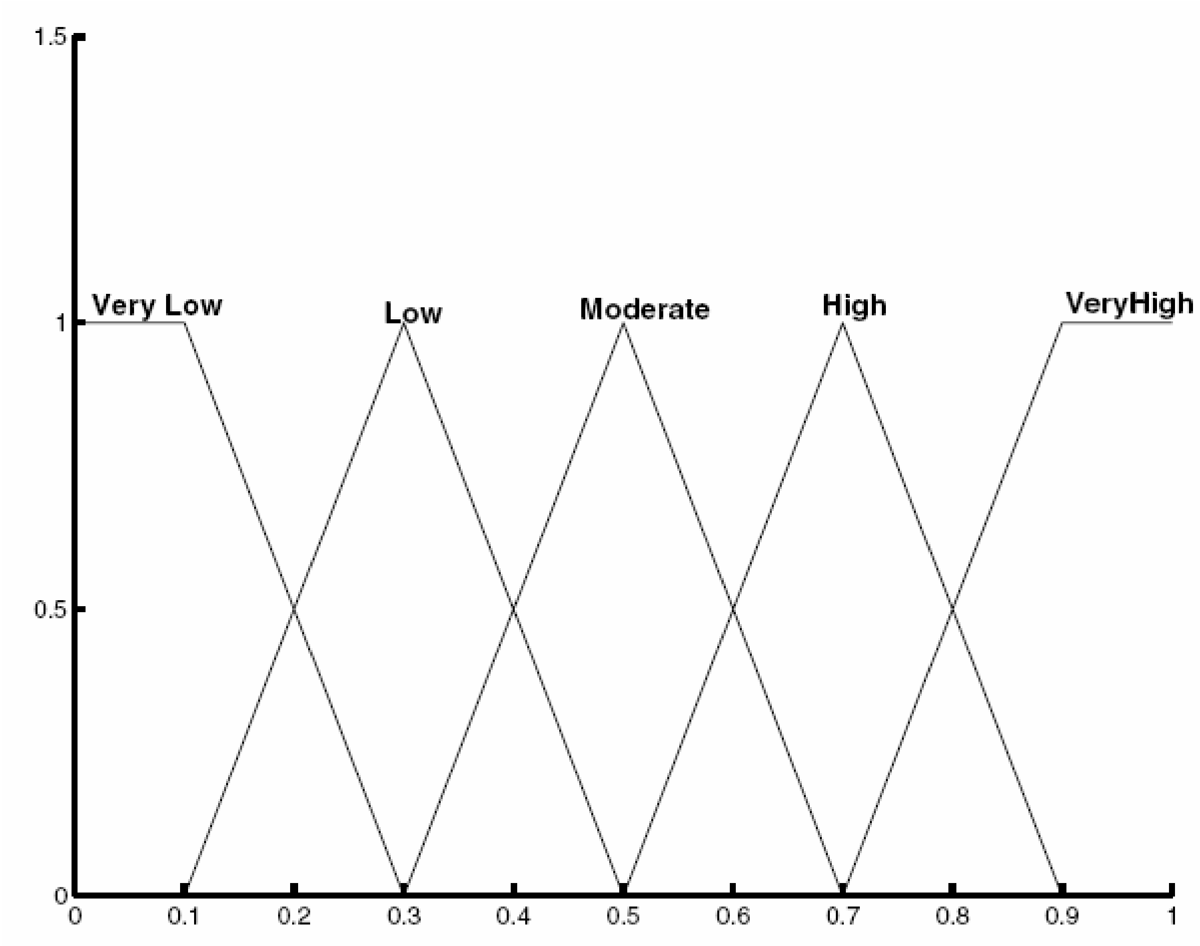
$\frac{n-2}{n}\%$ Successful transmission rate

Rules for Time Slot Allocation

- Ante1: traffic arrival rate
- Ante2: unsuccessful transmission rate

$Rule$	$Antecedent1$	$Antecedent2$	$Consequent$
1	Low	Low	$Moderate$
2	Low	$Moderate$	$High$
3	Low	$High$	$VeryHigh$
4	$Moderate$	Low	Low
5	$Moderate$	$Moderate$	$Moderate$
6	$Moderate$	$High$	$High$
7	$High$	Low	$VeryLow$
8	$High$	$Moderate$	Low
9	$High$	$High$	$Moderate$

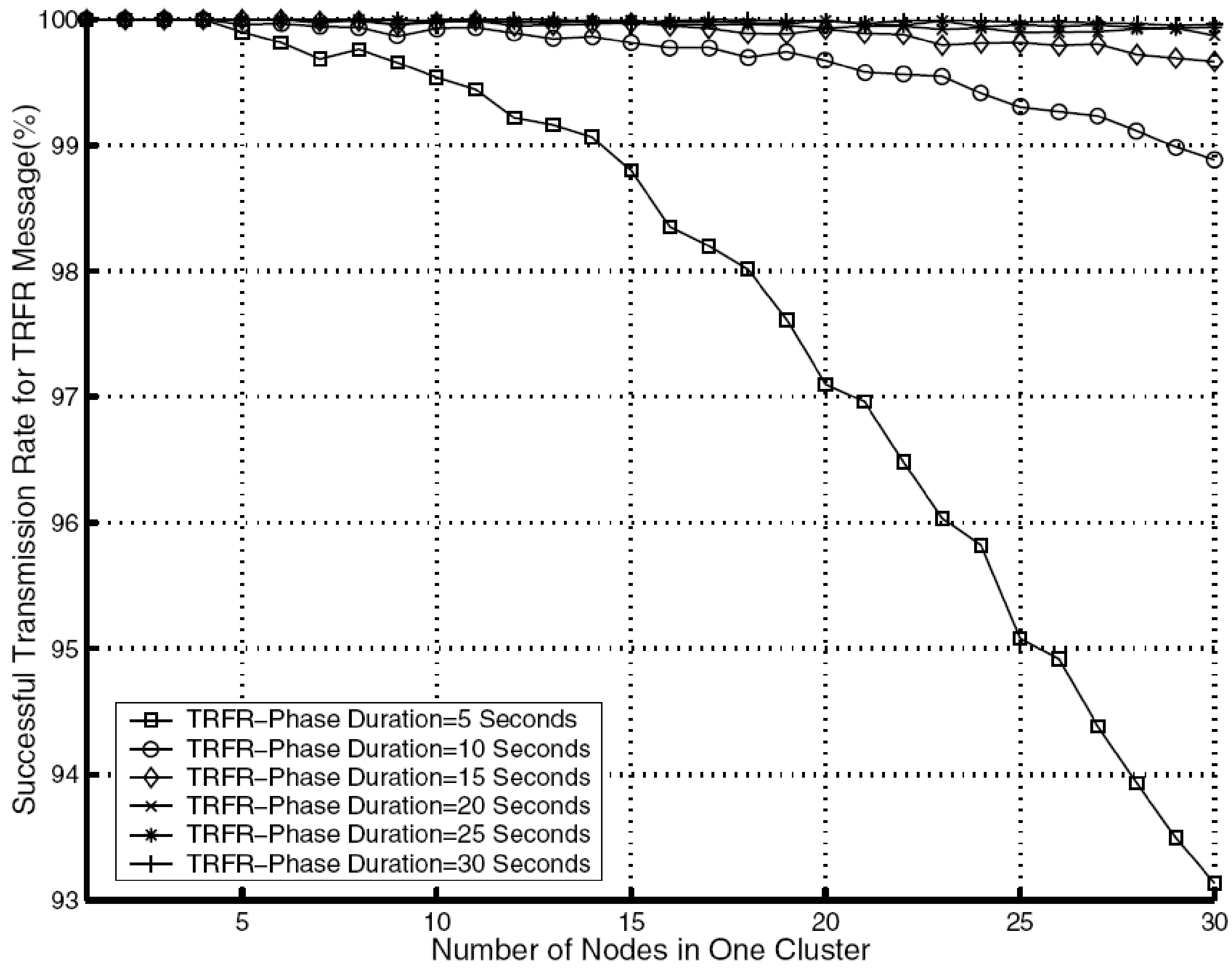
The MF of time-slot assignment



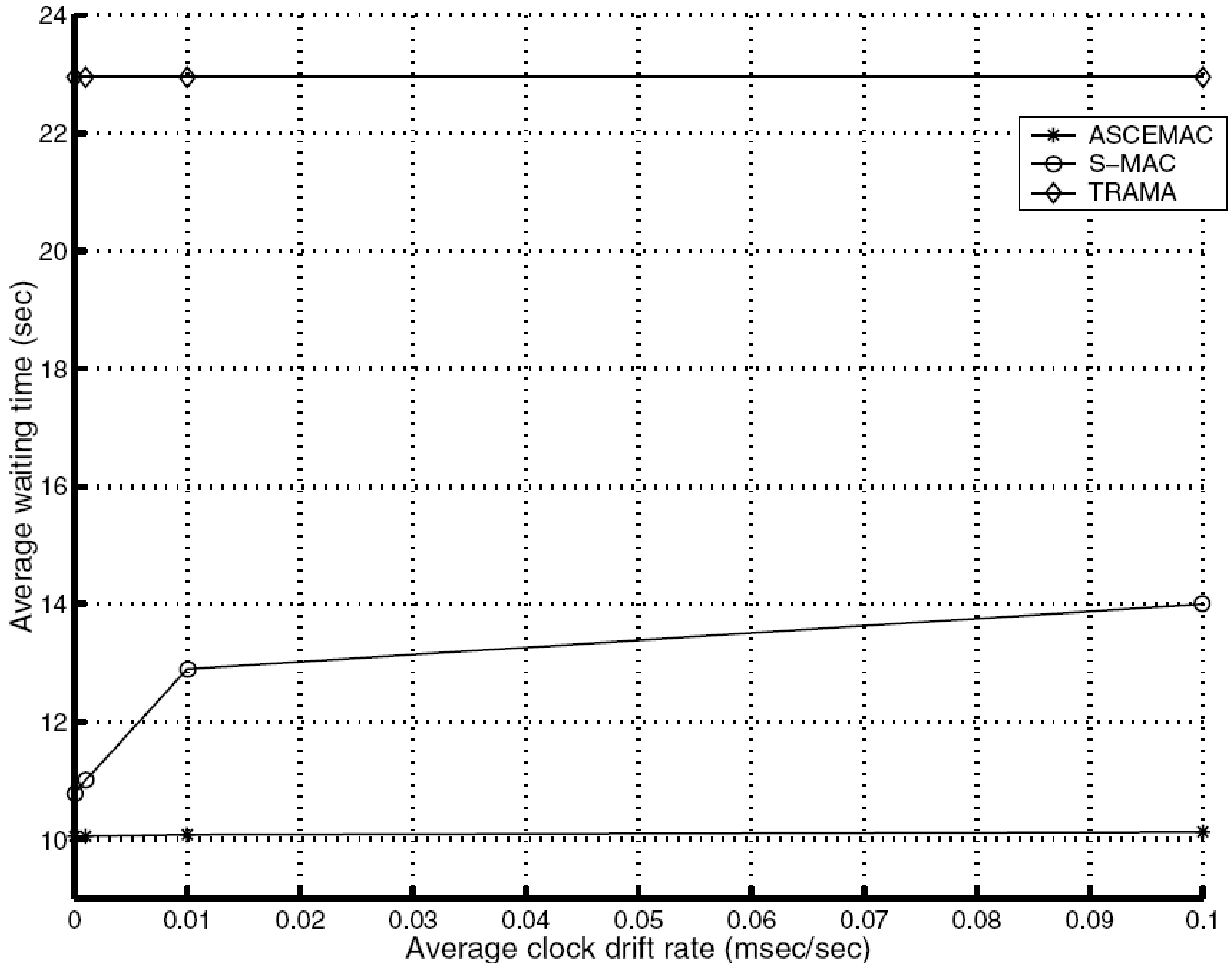
Simulation Environment

Simulator	OPNET
Area	100m x 100m
Radio range	30m
Symbol rate	40 Ksps
Data frame length	1024 bits
Clock drift range	1 to 100us

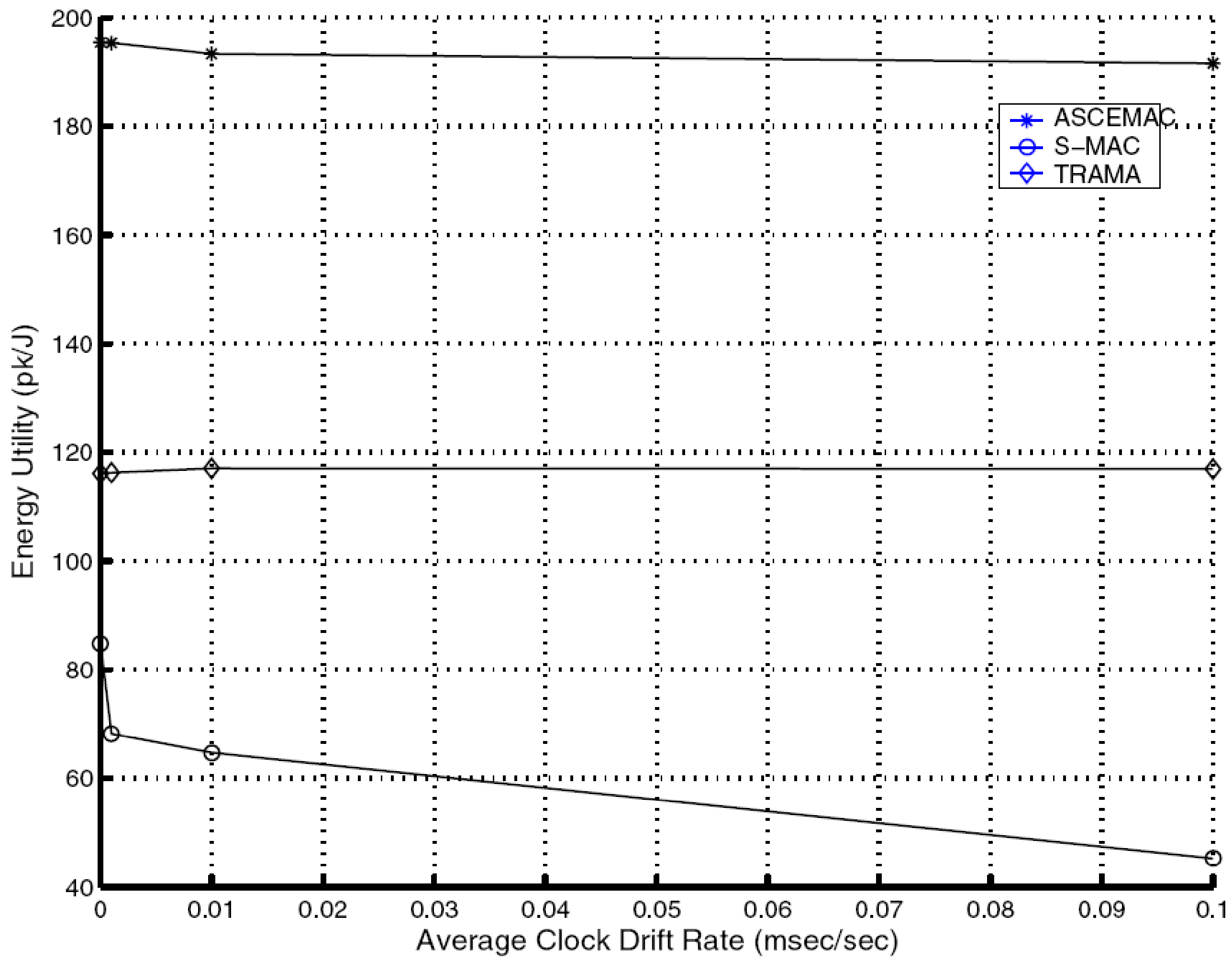
Successful Transmission Rate



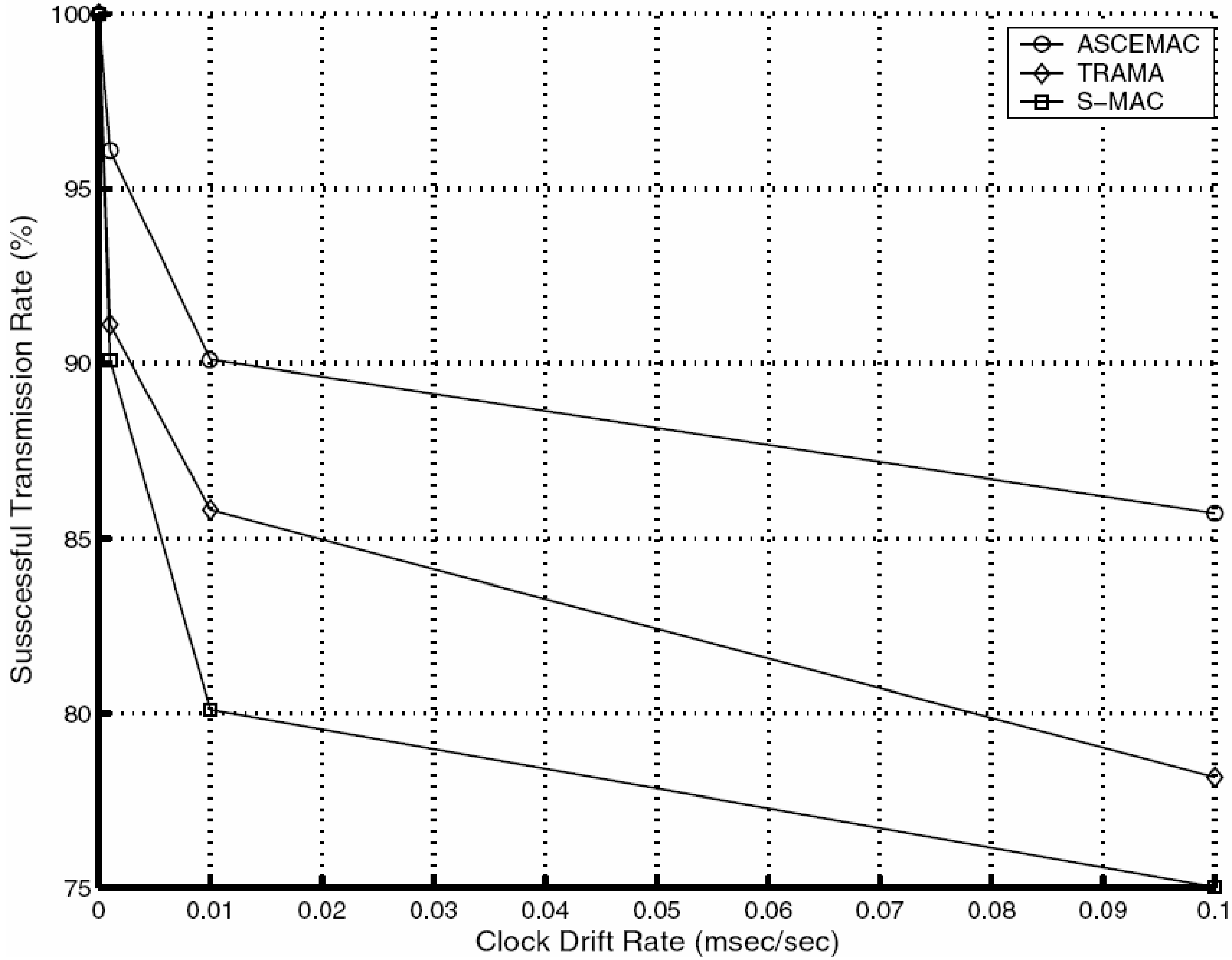
Average Waiting Time



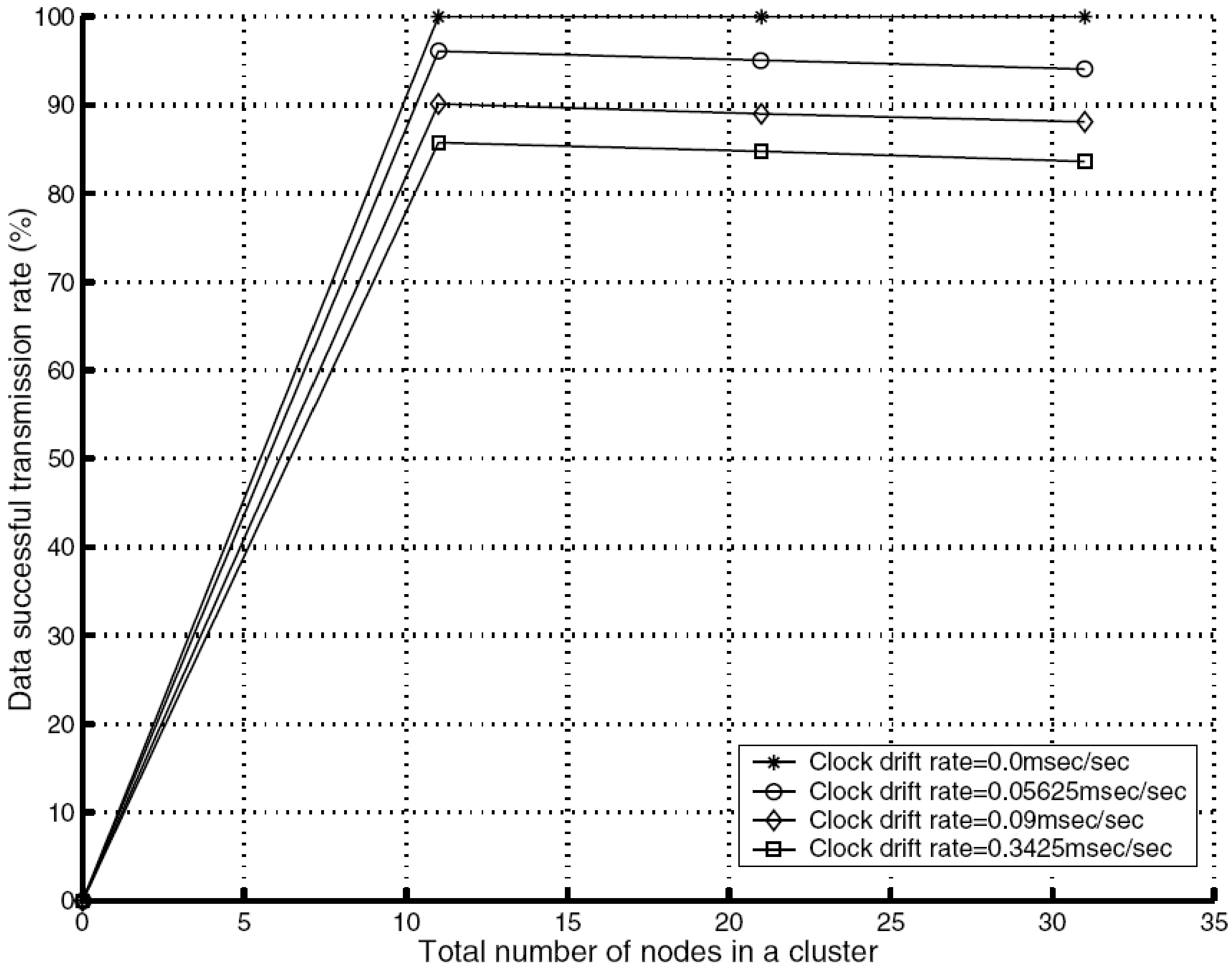
Average Energy Utility



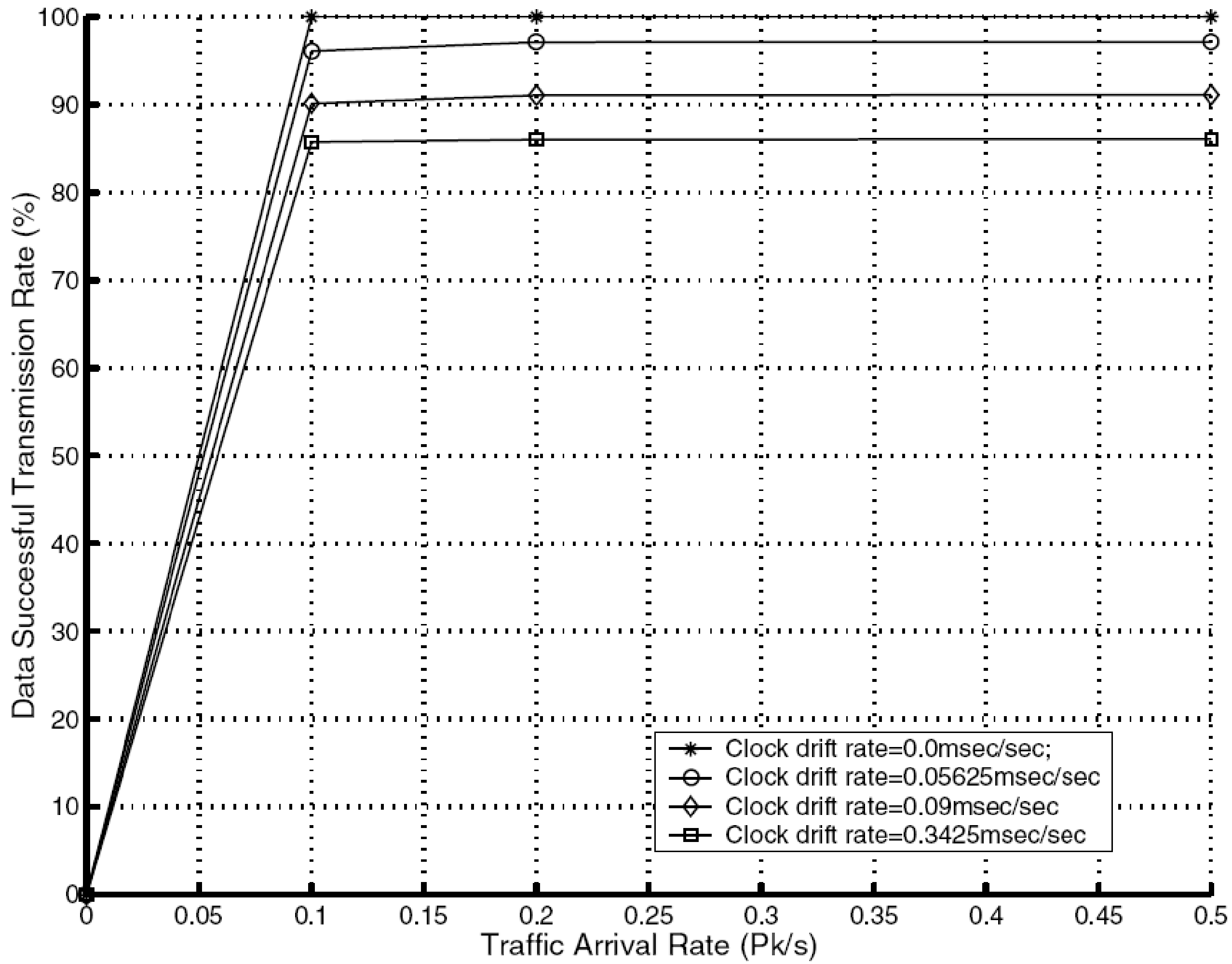
Successful Transmission Rate



Node Density Adaptation



Traffic Strength Adaptation



Conclusions

- Exploiting a rescheduling method, instead of time synchronization, to handle mismatch caused by clock drifts, as well as taking advantage of fuzzy logical theory, which has distinctive capabilities for coping with uncertainty
- ASCEMAC acquires the optimal values of essential algorithm parameters
  - Ensure average successful transmission rate
  - Decrease the data packet average waiting time
  - Reduce energy consumption

THANK YOU