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Algorithm for Introducing Adaptivity to MAC Protocols According to the Traffic Type in Wireless Sensor Networks

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ABSTRACT: *Different protocols have been proposed in literature, in order to minimize the energy consumption. While minimizing energy consumption, all most, all these protocols also try to achieve high throughput and packet delivery ratio; and low end to end latency. All these protocols are for either of the two types of traffic scenarios, synchronous or asynchronous. There may be situations where the traffic pattern may change from synchronous to asynchronous or vice versa. This work aims to introduce adaptivity according to the traffic pattern rather than traffic load.*

Keywords- *WSN*

1. INTRODUCTION

WSN technology has gained importance due to its potential for supporting a wide range of applications such as military operations, industrial, surveillance, targeting systems, health needs, monitoring disaster areas and many others. Wireless sensor networks consist of a large number of distributed nodes which are usually deployed in such an environment where it is inconvenient or almost impossible to recharge or replace the power sources of these nodes. These nodes are supposed to be microelectronic devices, which are equipped with limited power sources. Thus, the lifetime of such types of networks strongly depends on the battery lifetime of the sensor nodes. Therefore, in order to extend the network life time as long as possible, it is required to adopt an efficient power management mechanism for these nodes with the aim of providing the best performance at less amount of energy consumption.

Two kinds of traffic patterns have been discussed in the scenario of wireless sensor networks- periodic traffic and aperiodic traffic. Periodic traffic pattern is that in which traffic is generated on regular intervals on each of the nodes, and the aperiodic traffic pattern is that in which traffic is generated irregularly and suddenly. Therefore two different kinds of MAC protocols are employed for two different kinds of traffics. As sleep scheduling use to be an integral part of any wireless sensor network, the duty cycle of sleep schedules differs largely for two kinds of traffic patterns. The duty cycles employed for periodic traffic use to be comparatively larger than that employed for aperiodic table. In case of periodic traffic, nodes keep waking for a significant duration of time, at regular intervals, and keep sending data in this interval itself. On the other hand, in case of aperiodic traffic, nodes wake only for a small duration of time, and if no data is sensed, they go back to sleep for a long duration. However, if some data is sensed, they extend their wake period into the sleep duration, until the entire data is transmitted to the neighboring node.

A number of different protocols have been proposed, in literature, for both of these kinds of traffic patterns. Following section discusses about such protocols in some detail.

2. LITERATURE REVIEW

As outlined by [2], one of the most important constraints on sensor nodes is the low power consumption requirement. Therefore, while traditional networks aim to achieve high quality of service (QoS) provisions, sensor network protocols must focus primarily on power conservation. As mentioned by [4] a sensor node has a finite energy reserve supplied from a battery. It is often unfeasible to recharge the node's battery. Thus, the design of a wireless sensor network should be as energy efficient as possible.

Wei Y e et al in [5], while proposing their noble S-MAC protocol, specify that energy conservation and self-configuration are primary goals, while per-node fairness and latency are less important. The authors have also pointed out the various causes of the energy waste and have proposed a virtual clustering based protocol to minimize it.

The main causes of the energy waste are 'idle listening, overhearing, collision and control overhead', as pointed out by [5] [6] [7].

Dam Tijs van et al in [10], have proposed an adaptive energy efficient MAC protocol for Wireless Sensor Networks, named T-MAC. T-MAC is a contention based medium access protocol and is an enhanced version of the S-MAC [5]. It adds adaptivity to the previous one according to the load, while preserving the virtual clustering feature of the previous one.

Liu Yang et al in [11], have proposed an energy efficient QoS aware media access control protocol for wireless sensor networks, which minimizes the energy consumption in multi-hop wireless sensor networks (WSNs) and provides Quality of Service (QoS) by differentiating network services based on priority levels. The priority levels reflect application priority and the state of system resources, namely residual energy and queue occupancies.

Nam Yongsub et al in [13], have designed an adaptive MAC (A-MAC) protocol for those kind of wireless sensor networks which are required to survive for a pre- configured lifetime. In terms of authors the protocol has a two-fold concern: guaranteeing the pre-configured network lifetime, and reducing end-to-end latency. In order to achieve both goals, A-MAC introduces an adaptive duty cycle depending on ratio of the remaining energy to the initially supplied energy considering the pre-configured lifetime.

Schurgers C. et al in [14], Gu Lin et al in [15] and Dhanaraj M. et al in [16] have taken a completely different approach to achieve energy efficiency. They have talked about using a different radio channel, called ‘wake-up radio’ to wake-up the sensor nodes, when some of the data is required to be transmitted to them. Such kinds of approaches do not require scheduling of nodes for sleeping and waking periods.

Gu Lin et al in [15], have pointed out that the wake-up/sleep scheduling approach has some disadvantages. First, the design of a good wake-up/sleep schedule is often application dependent and complicated. Hence, it is hard to design a general power management service based on wake-up/sleep scheduling. For each application, the designer needs to carefully analyze the timing of the system events and tune the scheduling parameters; otherwise some nodes in the network may miss wake-up calls. Second, a good wakeup/sleep schedule often involves collaboration among a group of nodes, or even all the nodes in the network. This often implies that the network needs a time synchronization service. With low-speed processors and radio communication links, to perform high-quality time synchronization in sensor networks is an even more challenging task than in traditional distributed systems. Finally, a common phenomenon is that, in most of the wake-up periods, no event happens and the nodes enter sleep mode again. This means that nodes wake up too often, and it is a waste of energy.

Dhanaraj M. et al in [16], have raised the point, that such dual channel energy efficiency protocols increase the latency encountered in setting up a multi-hop path. They have proposed in their paper, a reservation scheme based protocol, called Latency minimized Energy Efficient MAC protocol (LEEM), which is a novel hop-ahead reservation scheme in a dual frequency radio to minimize the latency in the multi-hop path data transmission by reserving the next hop’s channel a priori. Simulation results show that LEEM consumes lesser power and reduces end-to-end latency by around 50% than that of the existing schemes.

Tan Wee Lum et al in [22], have taken a completely different approach- ‘A Receiver-Driven MAC Protocol’. This Receiver-Driven MAC Protocol, called RMAC, is a TDMA based MAC protocol in which the ownership of the timeslots is in the hands of the receiver nodes and here the receiver nodes assign the timeslots to their neighboring sender nodes. By doing so, the RMAC not only eliminates the need for the sender nodes to explicitly wake-up a receiver node for data transmission, but also eliminates any collision or contention overhead among the sender nodes. The simulation results show, that the RMAC outperforms the other sender driven, TDMA-based MAC protocols in terms of the packet latency and power consumption.

Joohwan Kim et al in [24], have focused on the event-driven asynchronous sensor networks with low data rates. They have worked on minimizing the delay and maximizing the lifetime of such networks, for which events occur infrequently. In such systems, most of the energy is consumed when the radios are on, waiting for a packet to arrive. As said by the authors, sleep-wake scheduling is an effective mechanism to prolong the lifetime of these energy-constrained wireless sensor networks. However, sleep-wake scheduling could result in substantial delays because a transmitting node needs to wait for its next-hop relay node to wake up. An interesting line of work attempts to reduce these delays by developing “anycast”-based packet forwarding schemes, where each node opportunistically forwards a packet to the first neighboring node that wakes up among multiple candidate nodes.

Ammar Ibrahim et al in [25], have again picked S-MAC, one of the very initial protocols for wireless sensor networks and modified it for high traffic loads. As quoted by the authors, "S-MAC is a popular protocol designed specifically for WSNs with low duty cycle operation. At its inception, S-MAC has been designed for low traffic loads. In this paper, we propose an enhanced version of S-MAC, called PS-MAC, that shows to support comparatively higher traffic levels while achieving the better energy efficiency. This is achieved using the parallel transmission concept." Thus the concept of parallel transmission is used in the proposed protocol by the authors.

Like Joohwan Kim et al in [24], Tan Hwee-Xian et al in [26] also, have focused on wireless sensor networks which are event driven i.e. which deal with asynchronous kind of traffic. As pointed by Joohwan Kim et al in [24], that the anycast is a good scheme of minimizing delay that occurs due to the sleep scheduling, Tan Hwee-Xian et al in [26] also have used anycast for minimizing delay in event driven wireless sensor networks. The protocol features independent and random wakeup schedules for each node; adaptive duty-cycles based on network topology; and adaptive anycast forwarders selection. All the other existent protocols do not individually vary the duty-cycle of each sensor according to local connectivity status, to maximize energy savings. The protocol, proposed by the authors of this paper, adds adaptivity, in the sense that the nodes can vary their duty cycles and forwarders' set. Nodes vary their duty cycles and forwarders' set in such a way that the energy consumption can be locally minimized for a given local delay performance objective. The proposed protocol also enhances the concept of cooperatively working in order to reduce the duty cycle of forwarding node. Both these mechanisms jointly result in better energy-latency tradeoffs and extended node's lifetime.

Sun Yanjun et al in [28], have proposed a novel protocol, called DW-MAC, i.e. Demand Wakeup MAC protocol. This protocol also, is a modification of the basic S-MAC protocol [9]; or a variation of the T-MAC protocol [10]. Both the T-MAC and the DW-MAC, add adaptivity to the novel S-MAC protocol, in terms of varying duty cycle for varying traffic. Though both have the same purpose, they differ in their mechanisms; and because of this difference the T-MAC where trades off maximum throughput for low energy consumption in case of low traffic, the DW-MAC increases effective channel capacity. Because of this increased capacity the DW-MAC achieves low delivery latency under a wide range of traffic loads including both unicast and broadcast traffic.

Lei Tang et al in [29], have found a new way of minimizing energy consumption. It is by predicting the receiver's wake up time. The protocol proposed, is named as Predictive Wakeup (PW) MAC protocol. The usability of the proposed protocol is, in the networks with asynchronous kind of traffics. The authors of the literature have also proposed an on-demand prediction error correction mechanism that effectively addresses timing challenges, such as unpredictable hardware and operating system delays and clock drift in order to enable accurate predictions. The authors have also introduced an efficient prediction-based retransmission mechanism, under the same protocol in order to achieve high energy efficiency even when wireless collisions occur and packets must be retransmitted.

Lei Tang et al in [30], have proposed a multichannel scheme for achieving energy efficiency. Named as EM (Efficient Multichannel) MAC, the protocol addresses many of the challenges faced by wireless sensor networks, such as wireless interference or even possible wireless jamming attacks. The protocol addresses these challenges through the introduction of novel mechanisms for adaptive receiver-initiated multichannel rendezvous and predictive wake-up scheduling. EM-MAC substantially enhances wireless channel utilization and transmission efficiency while resisting wireless interference and jamming by enabling every node to dynamically optimize the selection of wireless channels it utilizes based on the channel conditions it senses, without use of any reserved control channel. EM-MAC achieves high energy efficiency by enabling a sender to predict the receiver's wake-up channel and wake-up time.

3. COMPARISON

Review of literature as in above section shows that a number of different protocols have been proposed for both kinds of traffics. Following table lists all the kinds of protocols as viewed in literature in a comparative way.

Table 3.1 Comparison of various protocols

S. No.	Type of Protocol	Examples
1.	Adaptive protocols	T-MAC [10], Q-MAC[11], A-MAC[13], DW-MAC [28]
2.	Dual or Multi – channel protocols	As proposed by [14], [15], [16], [30]
3.	Receiver Driven Protocols	RMAC [22]
4.	Event Driven Protocols	As proposed by [24], [26], [29]

Event driven protocols are small duty cycle protocols, in which nodes sleep for a long and wake for a small duration. Such protocols are for those scenarios where data is not required to be sent periodically; in fact the data is not present all the time, it is generated eventually, rather. When generated and sensed, the nodes prolong their duty cycle according to the need.

All the adaptive protocols vary their duty cycles as per the desired goal. Such as T-MAC varies, its duty cycle according to the traffic load. For heavy traffics, it increases its wake period and for low traffics it shortens it. The Q-MAC varies its duty cycle according to the type of service required. The A-MAC adds adaptivity to the duty cycle according to the residual energy. DW-MAC adds adaptivity according to the traffic load, like T-MAC, but in a different way to achieve throughput efficiency as well, that T-MAC lacks.

But, it is well to notice, as mentioned by Gu Lin et al in [15] that the design of a good wake-up/sleep schedule is often application dependent and complicated. Hence, it is hard to design a general power management service based on wake-up/sleep scheduling. For each application, the designer needs to carefully analyze the timing of the system events and tune the scheduling parameters; otherwise some nodes in the network may miss wake-up calls.

In view of the remarks made by Gu Lin et al in [15], this paper emphasizes on the need of application specific MAC protocols for wireless sensor networks. Requirement of adaptivity is another demand of these MAC protocols. All the adaptive protocols discussed above, vary their duty cycles according to the traffic loads, residual energy or other QoS requirements. None of the protocols (up to the knowledge of the author) consider the application or the scenario in which the wireless sensor network is laid.

A number of such examples exist in real world in which the scenario or the need of the application changes. Such changes demand a change in the basic behavior of the protocol, running on the sensor nodes. All the adaptive protocols designed so far do not change their pattern; rather they work only with minimizing or maximizing duty cycles.

Therefore, while considering such applications, there exists a need of designing an adaptive protocol that changes its behavior according to the kind of traffic pattern. It is also required from the protocols come to their original form after completing their work, i.e. the adaptivity introduced, need to be bidirectional.

This has been aim of this work to introduce adaptivity according to the traffic pattern rather than traffic load.

4. PROPOSED SCHEME

The proposed scheme works initially with the basic S-MAC protocol, preserving its basic feature of virtual clustering. Achieving smaller delays, in the case of asynchronous traffic, use to be the aim of all the aperiodic or event driven protocols. The S-MAC runs with periodic sleep scheduling.

The proposed scheme works under two situations:

- First, when only periodic traffic is being generated on the sensor nodes; and
- Second, when aperiodic traffic has also been generated.

The scheme works in such a way that on generation and sensing of asynchronous data, the nodes dump their periodic scheduling and wake until the next neighbor search process in order to transmit this data to the sink, soonest possible.

The proposed algorithm works under three phases as discussed below.

4.1 Neighbor Search Phase

This is a phase of maximum of three second duration and repeats after each of the ten seconds. On the beginning of each of these phase nodes select their sleep schedule and share it with their neighbors. To preserve the virtual clustering feature, nodes do the same as in S-MAC. The algorithm is as follows:

1. Nodes select some sleep schedule, randomly.
2. They wait for a random amount of time.
   - If, in this wait period, they receive a schedule from any other node, then
     i. They delete their own schedule,
     ii. Accept this received one as their own schedule, and
     iii. Broadcast this schedule as their own to the medium, so as to reach to their neighbors.
     iv. Start a timer of ten seconds.
   - If, on the other hand, they do not receive any schedule, in this wait period, then
     i. They accept their selected schedule as their own, and
     ii. Broadcast this schedule to the medium, so as to reach to their neighbors.
     iii. Start a timer of ten seconds.
3. In either of the two cases discussed under (2), nodes save information of all the nodes, they receive from. In this way nodes keep a record of all their neighbors, along with their corresponding sleep schedules.
   - If the node is following any other's schedule, then the first node in the neighbors' list, is the one whose schedule it is following.
   - Otherwise, the first node in the neighbors' list may be any other neighboring node.
4. Nodes select their first neighbors, from the neighbors' list, as their intended receiver.
   - In the case, node following other's schedule, the node and its intended receiver, form the same virtual cluster.
   - In the case, node following its own schedule, the node and its intended receiver, lie in different virtual cluster. Such nodes work as bridge between two virtual clusters.
5. On the expiration of the timer,
   - Nodes clear their memory, and
   - Go to stage '1'.

4.2 Data Transmission Phase

1. After waiting for an accepted duration of time in neighbor search period, nodes start sleep schedule.
2. This step consists of either of the following two cases:
   - While sleep period, they switch off their radio and do not receive any data or synchronization signals.
   - In wake period, they
     i) Check for the sensed or received data in their memory.
     ii) If yes, then estimate the next wake up time of their intended receiver.
     iii) Wait for the estimated duration for receiver to wake up.
     iv) Contend for the medium, by means of RTS and CTS signals,.
   - On winning the contention, they
     i) Turn off their sleep/wake timer.
     ii) Start duplicate sleep/wake timer.
     iii) Occupy the medium for duration, equal to whole of their data duration.
     iv) If they find their data duration more than their wake period, then they extend their wake period into the sleep period.
     v) After finishing with whole of the data transmission, they resume their original sleep/wake timer.
   - Nodes, that do not win the contention
     i) Start their NAV timer.
     ii) Switch off their radio for the NAV duration.
     iii) Go to sleep if their sleep cycle comes.
   - The receiver node, on the other hand, does the steps (i), (ii) (iv)and (iv) of the winner node.

4.3 Aperiodic Traffic Generation Phase

If a node senses aperiodic traffic generated around it, it does the following:

1. It turns off its sleep/wake timer.
2. Checks the neighbors list to find the neighbor that is either waking or going to wake first.
   - If the neighbor is waking, then it contends for the medium,
   - Else,

i) it waits for the neighbor to wake; and then

ii) Contends for the medium.

3. On winning the contention, it sends the information to the fastest waking neighbor, putting a code into the information data packet.
4. Starts wait timer of predefined duration and waits for acknowledgement to come.
5. Nodes in the neighborhood, that here this information, but are not the intended receiver of the information
   - Turn off their sleep/wake timer.
   - Stop contending for the medium.
6. The receiver node
   - Sends the acknowledgement; and
   - Does the steps '1' through '4' of this section.
7. If acknowledgement is received, then
   - Node cancels its timer, and
   - Does not send the information if it is received again.
8. If, on the other hand, the timer expires, then the node resends the information by repeating the steps '1' through '4' of this section.

5. PROTOCOL IMPLEMENTATION

The modeled WSN has been simulated under OMNeT++ 4.3 platform. Each of the simulation is done once with the original S-MAC protocol and then with the event driven traffic generated on one of the nodes. The model is run for 1000 simulation seconds. In these studies, results are recorded in the result files generated by OMNeT++4.3. In these files, average delay of the entire network, overall throughput, average delay from individual nodes and the throughput of individual nodes are recorded.

***Network topology*:** The network consists of 25 nodes, which are laid in a grid topology. The distance between two one-hop away neighbor nodes, is 200 meters, which is the maximum transmission range of nodes. This means that the nodes can talk, only with their one-hop away neighbors. There is one sink near node no. 4. The conceptual model is shown in figure 5.1

Traffic model: Every non-sink node keeps sending a 100 bytes packet towards the sink node. The message generation time varies from 10 seconds to 1 second.

Energy model: All the nodes used in simulation have finite energy of 1000 joules. The different levels of energy consumption for different operations are defined in the following:

• idle state: 1.0 watt

• sleep state: 0.001 watt

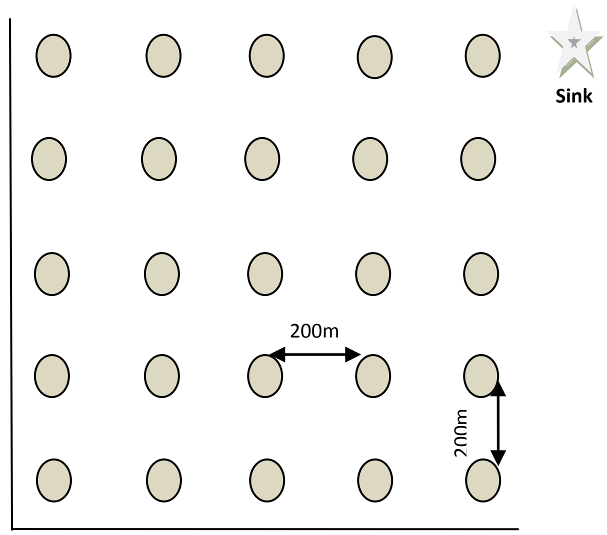

Figure 5.1 Network Topology

• state transition from sleep to idle: 0.01 watt

• transition time (sleep to idle): 0.01 sec

• receive power: 1.0 watt

• transmit power: 2.0 watt

Routing: Static routing (NOAH protocol) is used in the simulations. Using static routing allows to focus on MAC layer energy efficiency and to get rid of the effect of routing protocol.

Data Period: The transmission rate used here is that of 19.2 kbps, which implies a data period of 0.04s, for a packet of 100 bytes.

6. RESULTS

The protocol is run with 50%, 40% and 30% duty cycles. The results are recorded, for average delay from particular nodes and overall system throughput, for periodic traffic and for event driven traffic also generated.

6.1 Average Delay

Following figures show the curves for average delay for three different nodes for 50%, 40% and 30% duty cycles respectively.

It is apparent from figures 6.1, 6.2 and 6.3 that the delay encountered for aperiodic traffics is much – much less than the delay encountered for periodic traffics. It is also clear that the delay is also affected by the duty cycle, time of asynchronous traffic generation and the position of node relative to the sink.

It is clear from figure 6.2 that the delay for asynchronous traffic is very less (nearly zero), when the asynchronous traffic is generated in the beginning of the simulation.

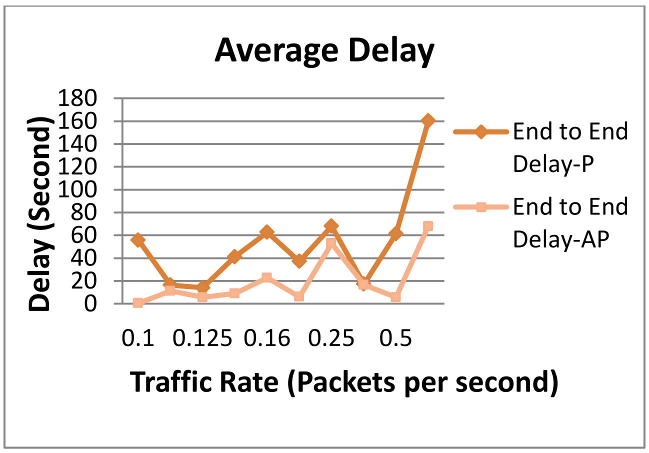

Figure 6.1: Average Delay for node 1 for 50% duty cycle and Aperiodic Traffic generated at 582.019791239872s

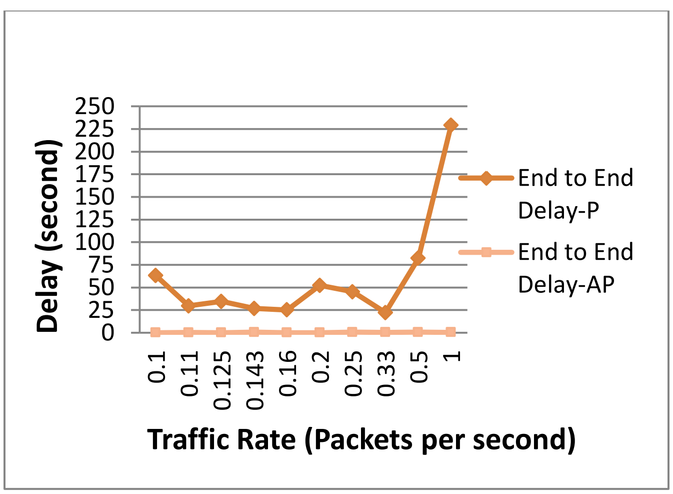

Figure 6.2: Average Delay for node 12 for 40% duty cycle and Aperiodic Traffic generated at 65.709538757801s

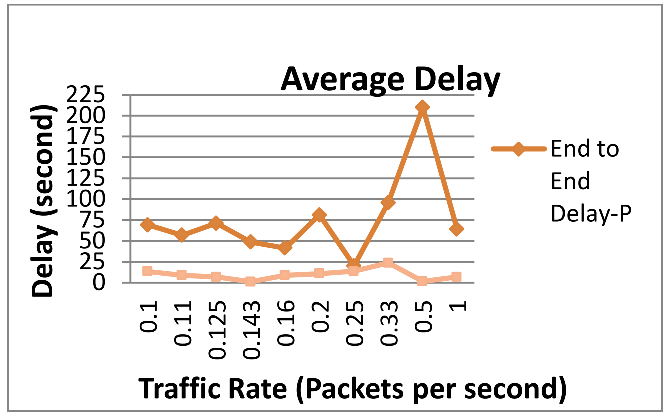

Figure 6.3: Average Delay for node 2 for 30% duty cycle and Aperiodic Traffic generated at 448.8257796833261s

6.2 System Throughput

Following figures show the curves for overall system throughput for three different nodes for 50%, 40% and 30% duty cycles respectively.

It is clear from figures 6.4, 6.5 and 6.6 that the throughput falls considerably on the occurrence of asynchronous traffic, especially for higher data rates.

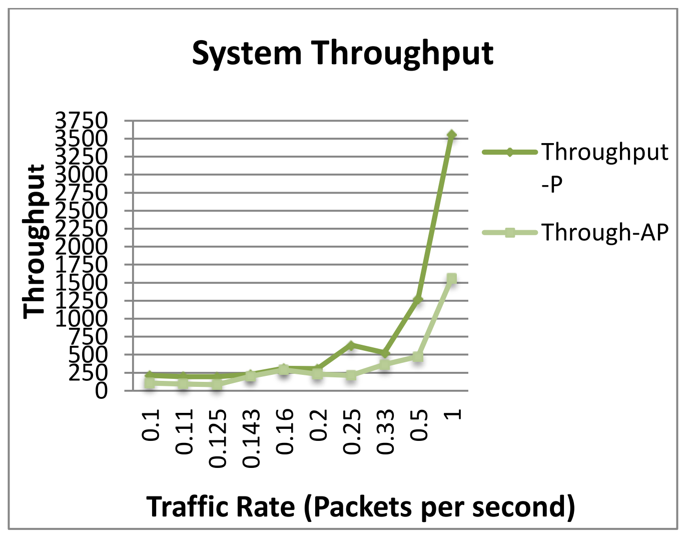

Figure 6.4: System Throughput for node 1 for 50% duty cycle and Aperiodic Traffic generated at 582.019791239872s

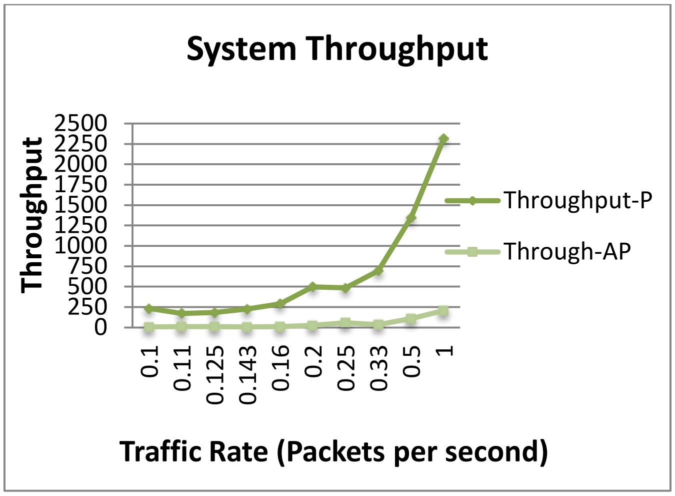

Figure 6.5: System Throughput for node 12 for 40% duty cycle and Aperiodic Traffic generated at 65.709538757801s

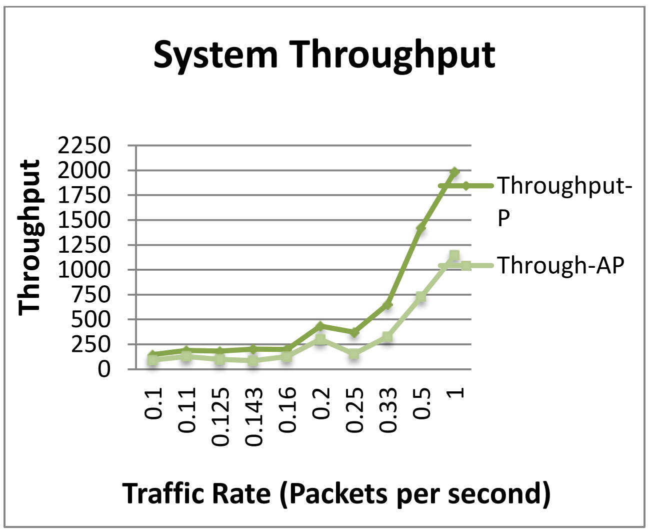

Figure 6.6: System Throughput for node 2 for 30% duty cycle and Aperiodic Traffic generated at 448.825796833261s

7. CONCLUSION

It is clear from the figures that the proposed scheme, achieves minimization in delay, on the generation of asynchronous traffic, to a good extent. The delay achieved is less than 100 seconds in all the cases and even less than 25 seconds for 30% duty cycle, case. The cost paid for achieving such small delays is the high fall in throughput for traffic rates above 0.25 packets per second.

The degradation in the throughput response is because of unidirectional information flow. Extending the algorithm for bidirectional information flow, will be the work to be done in future, in order to improve the throughput response.

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