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# WIRELESS MESH NETWORKS EMPLOY ADAPTIVE POWER AND ADAPTIVE RATE LINK SCHEDULING

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**Abstract:**Presented is a distributive heuristic algorithm designed to optimize network throughput in Wireless Mesh Networks (WMN) that employ adaptive power and adaptive rate spatial-time division multiple access (TDMA). This approach involves scheduling time slots based on the Signal-to-Interference and Noise Ratio (SINR), allowing data transmission at the most viable power and rate levels, all the while configuring the Modulation or Coding Scheme. Unscheduled transmitters engage in calculating the highest potential SINR achievable for their connections if they were scheduled in the subsequent slot. This iterative process continues until the power margins of the already scheduled links hinder the inclusion of further transmissions within the time slot. It is noteworthy that our algorithm attains performance levels approximately 5-10% lower than those demonstrated by a recently developed algorithm, albeit with a substantially reduced computational complexity.Additionally, it demonstrates energy efficiency and robustness by efficiently scheduling new sets of links on top of existing schedules.

**Keywords:** Adaptive Power, Adaptive Rate Spatial, Distributive Heuristic Algorithm, Noise Ratio, SINR, TDMA

## 1.INTRODUCTION

Within wireless multi-hop mesh networks, scheduling-oriented Medium Access Control (MAC) protocols, such as spatial-TDMA, are harnessed to allocate exact time slots for stations to effect message transmission. The optimization of network output hinges on the creation of a timetable that accommodates multiple high-rate simultaneous transmissions during a single time slot. Contemporary stations enhance the effectiveness of both physical and MAC layer processes by implementing adaptive radios. These radios autonomously opt for the appropriate Modulation or Coding Scheme (MCS) and Transmission Data Rate (TDR) on a per-time-slot basis. Concurrently, the quest for elevated throughput also underscores the importance of fine-tuning the convey power level of scheduled stations in concurrence with the data rate selection for every individual time slot.

Significant efforts have been focusedon devising a machine to determine the simultaneous distribution of time slots and transmit power levels for active links, particularly in cases where a uniform transmission rate is employed for each link [1]. Notably, DPCS [2] has garnered significant attention within this realm. These algorithms operate through an iterative process where the transmitting end of each active link incrementally adjusts the transmit power. This adjustment factor is contingent on the ratio between the desired SINR and the actual SINR measured at the receiving end. For these algorithms to effectively converge towards a viable power configuration, a predefined set of links eligible for concurrent activity must be predetermined by a central controller. Moreover, it's worth noting that the practical implementation of this algorithmic category is confined by the upper limit of permissible transmit power values.

To maximize the effective utilization of network spectrum resources, we investigate the interplay between link scheduling, Network Coding (NC), and Channel Assignment (CA). We propose a two-phase solution approach that dynamically selects the transmission scheme in an adaptive manner. In the first phase, we introduce an NC-aware scheduling method that enhances network throughput by considering the interaction between NC and spatial reuse. As a result, interference-free links are grouped together in the same link set[3], enabling them to be activated in the same time slot and channel. In the second phase, we employ a heuristic method to assign different channels to the link sets based on the radio constraints of each node. This further improves network throughput.

## 2.RELATED WORKS

Rubin et al [4] presenting a pair of novel heuristic algorithms designed to optimize network output within adaptive power and adaptive rate spatial-TDMA wireless networks.The problem at hand involves finding an optimal joint link scheduling approach while simultaneously assigning transmit power stages and data rates to active links. Recognizing the NP-complete nature of this problem, we progress to develop two heuristic algorithms with polynomial complexity to efficiently address it.The first algorithm constructs a Power Controlled Rate adaptation Interference Graph and derives the desired schedule by employing a greedy algorithm to form an independence set from this graph.In the second algorithm, each time slot selects the transmission with the maximum SINR level at its intended receiver and then proceeds to iterate through the remaining transmissions. It aims to accommodate as many simultaneous transmissions as possible, with each operating at the maximum feasible data rate.Through system analyses and simulations on illustrative networks, observed that the second heuristic algorithm generally outperforms the first heuristic algorithm in terms of performance.

Hedayati et al [5] developed a new mathematical programming model and assignment algorithms with the aim of minimizing the schedule length in adaptive power and adaptive rate link scheduling within spatial-TDMA wireless networks. The problem involves optimizing the joint scheduling of transmissions across multi-access communication links while simultaneously allocating transmit power levels and data rates to active links. Additionally, we ensure that the required SINR levels are met by the intended receivers.We demonstrate that this problem can be represented as a MILP model, which provides a solution consisting of transmit power levels that are strongly Pareto Optimal. It is worth noting that this problem falls under the NP-complete category.For the purpose of comparison, we utilize the MILP formulation to compute the optimal schedule for networks with a small number of designated links and a limited range of data rate levels. Additionally, we develop and analyze a heuristic algorithm with polynomial complexity to solve the problem efficiently. This algorithm is based on constructing a Power Controlled Rate adaptation Interference Graph, and the desired schedule is derived using a greedy algorithm to form an independence set from this graph.

Meyer et al. [6] delve into the realm of adaptive multi-hop networks in the Industrial Internet of Things (IIoT) context, specifically addressing the challenges posed by time-varying and dynamically changing traffic patterns. It emphasizes the importance of efficient transmission of management traffic in achieving high adaptability within the IEEE 802.15.4 DSME protocol.To enhance adaptability, the dissertation develops and presents a range of techniques that are validated through a combination of simulations, hardware experiments, and analytical models. One notable technique, called Quality of Medium Awareness(QMA), effectively reduces collisions in management traffic by intelligently learning the optimal times for packet transmission. Additionally, the dissertation explores the benefits of sending two or more packets per Guaranteed Time Slot (GTS) and utilizing group acknowledgments, which help alleviate the burden on management traffic.Furthermore, the dissertation introduces dynamic Contended Access Period reduction (CAP reduction), which offers a fine-grained trade-off between management and data traffic. This technique enables flexibility in adjusting the distribution of resources based on the specific requirements of the network.

TR et al. [7] development of nanotechnology necessitates fast data transfer to overcome performance bottlenecks arising from shared memory modules and interconnecting fabrics. In this research, we propose a novel technique called Proactive Flow control using Adaptive Beam formation for Smart Intra-layer Data Communication (PF_SDC) specifically designed for Wireless Network-on-Chip in next-generation nano-domain technology. This technique aims to optimize network resources, ensure Quality of Service (QoS), and enhance data communication within the WiNoC framework.A hybrid NoC architecture is utilized to optimize application admission for data transfer, combining wired and wireless interconnects. The management of data traffic is handled by an Intelligent Head Agent (IHA) employing fuzzy inference. By predicting router status based on queue load, the IHA determines the most suitable path for data transmission. Additionally, the IHA initiates beam formations at specific angles to facilitate data flow towards the intended target, while minimizing network power consumption and resource utilization.Through simulation modeling, we demonstrate the practical applicability of the proposed system, showing low power consumption and high throughput. These results indicate the potential of the PF_SDC technique in real-world applications, effectively addressing the challenges of data communication in Wireless Network-on-Chip architectures for next-generation nanotechnology.

Sharath et al. [8] IoT network represents the future of connectivity, seamlessly integrating people and machines. It holds the potential to enhance human comfort and revolutionize various applications, smart homes, healthcare, security surveillance, and smart meters. Given that IoT nodes are typically battery-powered, it becomes crucial to optimize energy consumption to extend the network's lifetime. However, the presence of heterogeneous device capabilities, network dynamics, and varying application characteristics introduces numerous challenges and overheads in routing, leading to a faster depletion of energy resources. This energy imbalance significantly reduces the overall lifetime of the IoT network. To address this issue, this study proposes a clustering topology approach based on heuristics for the IoT network, along with a routing mechanism and transmission schedule specifically designed for the clustered topology. The objective of this proposed solution is to improve the network's lifetime while minimizing any notable degradation in terms of packet delivery ratio and delay. Through simulations conducted in NS2, the proposed solution demonstrates its effectiveness by increasing the network's lifetime by 20% compared to existing approaches.

## 3. PROBLEM STATEMENT

The heuristic algorithm [9] offers lower complexity while generally demonstrating comparable or superior performance related to the initial heuristic algorithm. Research has established the NP-completeness of finding thefinest solution for jointly assigning time slots, transmit power, and data rate stages across active associations. In wireless multi-hop mesh networks, MAC protocols like spatial-TDMA are utilized to distribute time slots for message transmission among stations. To achieve better network throughput, an ideal schedule should enable multiple high-rate simultaneous transmissions within a time slot. Considerable endeavors have been invested in formulating a mechanism for ascertaining the combined allocation of time slots and transmit power levels within the framework of utilizing a solitary transmission rate per link. Furthermore, an investigation delves into a class of DPCA.

***A SampleMesh Network:***Figure 1 illustrates a WMN comprising stochastic stations seeking intercommunication within a designated operating area. The network employs a shared MAC utilizing TDMA. The network is partitioned into a control sub-channel, used for scheduling transmissions, and a data sub-channel.

The stations in the system perform measurements to determine the communication channel's quality for each active link, obtaining propagation gain values. We focus on developing and analyzing algorithms for time slot assignments based on specific characteristics of the channel and user activity, such as loading stages and locations. It is assumed that these activity features remain largely unchanged throughout each operational period when the scheduling calculations are executed.

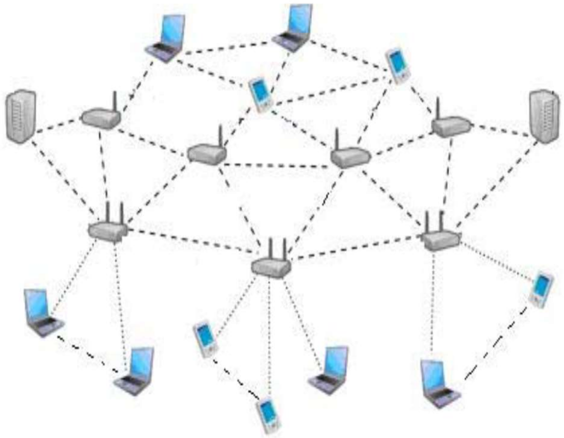


Figure 1: Sample mesh network

### 3.1Model of the system

Each node possesses the capability to continuously fine-tune its transmit power within a designated range [0, P$max$]. These nodes have the flexibility to transmit at diverse data rates drawn from the collection $R = \{r1, r2, \cdots ,rm\}$, where each rate corresponds to distinct modulation/coding schemes, aligned in ascending order of rates (i.e., r1 < r2 <⋯< rm). A node can engage in transmission toward a singular recipient over a link, and all nodes are outfitted with half-duplex radios and omnidirectional antennas that share similar attributes.

Operational synchrony is maintained via identical time slots, and the duration of a slot, $\tau s$, mirrors the transmission time of a packet (comprising overhead bits) at the lowest rate r1. Central to the operation is the task of allotting time slots within a defined timeframe for the transmission of packets along specific links.

Node i can establish a directed communication link (l$ij$) with node j within its communication range. This link requires the selection of a power level (P ∈ [0, $P$max]) to ensure that the SNR at node j meets or exceeds the threshold $\gamma(r1)$ necessary for satisfactory operation at the base rate r1. This requirement can be expressed as $GijP/N \geq \gamma(r1)$ (Equation 1), where $Gij$ represents the propagation gain, incorporating factors like fading and shadowing that contribute to effective power loss in the link, while N signifies the thermal noise power [10]. For simplicity, we consider $Gij$ to be equal to $Gj$. The set of communication links enabling the transmission of at least one packet is denoted as L. The propagation gain matrix is represented as $G = [G]$ and remains constant during operation.

***System Analysis and Design:***The purpose of system analysis and design is to fulfill the requirements outlined in the feasibility report. This phase involves defining the various components, modules, interfaces, and data necessary for the system to meet the specified requirements effectively.

***Performance Representations:***Within a wireless mesh network, where active stations strive for interconnectedness within a defined operational area, a shared MAC operates on a TDMA framework. This channel is partitioned into distinct control and data sub-channels; the former enables station interactions for transmission scheduling. Furthermore, these stations execute measurements to evaluate the quality of the communication network for active links, thus determining propagation gain values.

The crux of this paper revolves around the formulation and examination of algorithms geared toward the allocation of time slots. These algorithms hinge on specific characteristics of the channel and user activity, encompassing factors like loading levels and geographical locations. The assumption made is that these activity features remain relatively stable throughout each operational cycle when scheduling computations are undertaken.

In a packet-switched communication network, the network load stems from multiple data flows. Both the packet rate and the number of packets relayed across individual links during a scheduling period are contingent upon the network routing protocol and upper-layer functions. These computations translate the offered congestion load matrix into the requisite for scheduling transmission of K$ij$ packets over each link l$ij$, within the set L.

### 3.2 Centralized Heuristic Algorithms

We developed a pair of centralized heuristic algorithms to manage adjustments in power and rate for link scheduling. The first algorithm focuses on allocating time slots, power levels, and rate settings to active links. It achieves this by selecting a maximal independent set from an extended interference graph. Within this graph, nodes represent potential transmissions, each with various viable rate levels across active links.

On the other hand, the second centralized algorithm operates iteratively, coordinating transmissions among links based on the potential to achieve the highest receive-SINR. This approach allows transmissions to occur at the highest feasible rate within each time slot.

Notably, this second algorithm maintains lower complexity while generally delivering a performance that matches or surpasses the outcomes of the first heuristic algorithm.

Furthermore, we established that finding the optimal solution for simultaneously allocating time slots, transmit power, and data rate levels across active links falls into the NP-complete category due to its complex nature. Despite this complexity, our initial centralized heuristic algorithm shows impressive proximity to the optimal solution within various illustrative small networks.

## 4. PROPOSED SYSTEM

The system we present integrates effective and resilient distributive algorithms designed for the allocation of time slots, data rate configurations, and power level adjustments within a spatial-TDMA network featuring directed communication links. To assess their performance, we engage in a comparative analysis between our distributive algorithm and centralized heuristic algorithms.

Moreover, we underscore the robustness and energy efficiency inherent in our distributive algorithm. This is accomplished by introducing a new set of links into an established schedule, within a network where a portion of link loads has been modified. Through this demonstration, we spotlight the adaptability and dependability of our distributive approach in practical real-world scenarios.

***Modules:*** In this study, we explore three main modules:

i. Distributive Power control Rate adaptation Link scheduling (DPRL) algorithm.
ii. The Incremental Scheduling Scheme.
iii. Performance Evaluation

i. ***DPRL algorithm:*** We iteratively construct a feasible transmission set S(t) for each time slot. In each iteration, we incorporate an active link with the highest SINR in each neighborhood into the set S(t).

Imagine a wireless network where links are classified as neighbors if their transmitting nodes fall within each other's 2-hop communication range. For an initial evaluation of SINR distributions, all active link transmitters emit test signals at their maximum power level, denoted as $\mathrm{P}max$. In response, each receiving node measures the accumulated interference level it receives, while each transmitter computes the SINR value for its link, takinginto account the propagation gain towards its receiver and the interference level detected.

These calculated SINR values for each link are disseminated to all nodes in the link's neighborhood. Subsequently, every active transmitting node contrasts its link's SINR value with the broadcasted SINR values of other links in the vicinity. The node possessing the highest SINR value in the neighborhood designates itself as the winner. As the winner, it broadcasts its power margin and then calculates the maximum feasible transmit power level and data rate for its link, factoring in the absence of other authorized transmissions in its immediate surroundings.

Now, let's focus on a triumphant link, marked as "k," with a computed transmit power $\mathrm{P}max$ and the highest attainable data rate, R(k). Assuming minimal external interference, the transmitter of link k computes the minimum power level, $\mathrm{P}k{-}min$, required to attain the SINR threshold at its receiver when no other transmissions are scheduled in its vicinity. This is mathematically expressed as:$Pk{-}\min = (R(k))N\ /Gikjk$

The power margin for the link, $\Delta Pk$, is then derived as the difference between the chosen transmit power and the minimum essential power, ensuring the link can endure additional interference while still meeting its SINR objective at its allocated rate.

**Algorithm 1:DPRL**

```
Begin
1. Check if there are no links scheduled in the current time slot.
        a. If true, proceed to the next step.
        b. If false, exit the algorithm.
2. Transmitter of the unscheduled link transmits a test signal at the maximum power level,   Pmax.
        a. Calculate the maximum potential SINR value at the receiver of the unscheduled link.
3. While the SINR value of the unscheduled link is greater than or equal to the threshold value, r1, repeat the following steps:
        a. Unscheduled node broadcasts its calculated potential SINR value to its neighboring nodes.
        b. Among the nodes in its neighborhood, identify the node with the highest SINR value as the winner.
        c. The winner calculates its maximum feasible transmit power and rate level, along with the resulting power margin at its receiver.
        d. The winner transmits a control message at the calculated transmit power, announcing its power margin.
Exit
```

In the next iteration, we identify the next set of winners from each neighborhood and incorporate them into the schedule. For each link that remains unscheduled, the transmitter associated with it calculates the highest permissible transmit power level for the link. This calculation relies on the power margin levels announced by previously scheduled links in the same vicinity, along with their respective propagation gain values. Utilizing this information alongside the reported interference level from its receiver, each unscheduled transmitter then determines the maximum attainable SINR level at the receiver of its link.

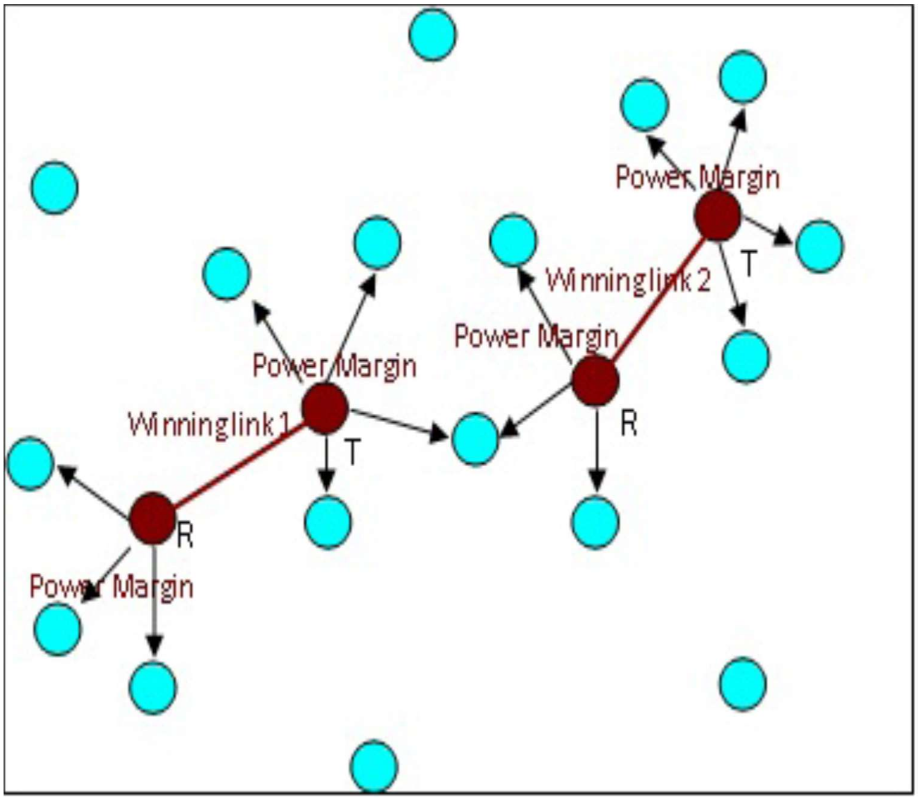


Figure2.The winner in each neighborhood announces its power margin.

***ii. The Incremental Scheduling Scheme:***A method employed to progressively schedule transmissions in a wireless network. Instead of assigning all time slots and link configurations at once, it incrementally adds links to the schedule over multiple iterations.

Initially, the scheme selects a subset of links based on certain criteria, such as link quality, traffic demands, or priority. These selected links are scheduled to transmit in their respective time slots. In subsequent iterations, additional links are chosen and scheduled, gradually expanding the set of active links.

Offers advantages in managing network dynamics, adapting to changing conditions, and efficiently utilizing network resources. By scheduling links incrementally, it can accommodate new link requests, account for fluctuations in link quality, and respond to varying traffic loads, all while maintaining an effective and flexible communication schedule.

**Algorithm 2: Incremental Scheduling**

**Input:**

- Set of all available links L
- Maximum transmit power level P$max$ for all links
- Set of active links S(initially empty)
- Set of scheduled links S_scheduled(initially empty)
- SINR threshold value γ

**Output:**

- Scheduled set of links S_scheduled

**Algorithm:**

```
    1. Initialize: Set S and S_scheduled to empty sets.
    2. Repeat until all links are scheduled:
        a. For each unscheduled link l in L:
        i. Calculate the SINR for link l based on the current schedule, including
        interference from links in S_scheduled.
        ii. If the calculated SINR for link l is greater than or equal to the threshold γ, add
        link l to set S.
b. Update S_scheduled by adding all links in S.
c. Remove all links in S from the set L.
d. Clear set S.
   3. Return the scheduled set of links S_scheduled.
```

***iii. Performance Evaluation:***Performance evaluation of wireless mesh networks is essential to understand how well these networks function under different conditions and scenarios. It involves measuring and analyzing various performance metrics to assess the network's efficiency, reliability, and scalability. Some key aspects of performance evaluation in wireless mesh networks include:

**Throughput:** Throughput measures the data transfer rate and is an important indicator of the network's capacity to handle data traffic. Evaluating throughput helps control how much data the system can transmit in a given time period.

**Latency:**Refers to the delay in transmitting data between nodes in the network. Low latency is crucial for real-time applications like video streaming and online gaming.

**Packet Loss:**Occurs when data packets are dropped during transmission. Evaluating packet loss helps gauge the network's ability to maintain data integrity and avoid data retransmission.

**Coverage and Connectivity:** Assessing the coverage area and connectivity of the network ensures that all nodes can communicate effectively and that there are no isolated regions.

**Network Capacity:** Evaluating the network's capacity involves determining the maximum number of nodes it can support while maintaining acceptable performance levels.

**Energy Efficiency:** Wireless mesh networks often rely on battery-powered devices. Performance evaluation includes analyzing energy consumption and the network's ability to optimize energy usage to prolong the node's battery life.

**Scalability:** Performance evaluation helps understand how the network's performance scales with an increasing number of nodes and traffic demands.

**Mobility:** For mobile wireless mesh networks, performance evaluation considers the network's ability to handle node mobility and maintain connectivity.

**Security:** Evaluating the network's security mechanisms, such as encryption and authentication, is crucial to ensure data privacy and protection against unauthorized access.

**Algorithm 3: Performance Evaluation**

**Input:**

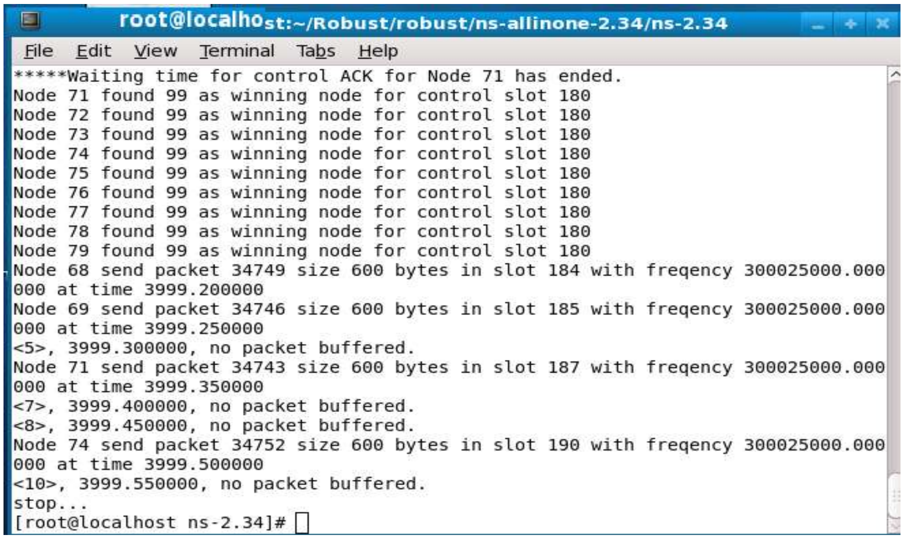
- Network topology and configuration
- Network traffic and application scenarios
- Wireless mesh network algorithm to be evaluated

**Output:**

- Performance metrics and analysis results

## 5.FINDINGS AND DISCUSSIONS

***Compiling and Running tcl Scripts:***Figure 3 depicts theinput.tcl file is compiled and it creates trace file (old.tr) and network animator (old.nam) files. Using pearl script (throughput1.pl) and trace file (old.tr) throughput is calculated with the help of the command. Later input.tcl is compiled and it generates new.tr and new.nam as trace files and network animator files. Using the same script (throughput1.tcl) and trace file (new.tr) again throughput is calculated. Finally, we run the network animator (new.nam) file, and its screenshot is shown onthe next page.



```
*****Waiting time for control ACK for Node 71 has ended.
Node 71 found 99 as winning node for control slot 180
Node 72 found 99 as winning node for control slot 180
Node 73 found 99 as winning node for control slot 180
Node 74 found 99 as winning node for control slot 180
Node 75 found 99 as winning node for control slot 180
Node 76 found 99 as winning node for control slot 180
Node 77 found 99 as winning node for control slot 180
Node 78 found 99 as winning node for control slot 180
Node 79 found 99 as winning node for control slot 180
Node 68 send packet 34749 size 600 bytes in slot 184 with freqency 300025000.000
000 at time 3999.200000
Node 69 send packet 34746 size 600 bytes in slot 185 with freqency 300025000.000
000 at time 3999.250000
<5>, 3999.300000, no packet buffered.
Node 71 send packet 34743 size 600 bytes in slot 187 with freqency 300025000.000
000 at time 3999.350000
<7>, 3999.400000, no packet buffered.
<8>, 3999.450000, no packet buffered.
Node 74 send packet 34752 size 600 bytes in slot 190 with freqency 300025000.000
000 at time 3999.500000
<10>, 3999.550000, no packet buffered.
stop...
[root@localhost ns-2.34]# 
```

Figure3.Compiling and Running tcl Scripts

***The output of NAM:*** Figure 4 displays the output of the network animator file (new.nam) with a total of 60 nodes. Nodes 0 and 9 serve as access points, while the remaining nodes have mobility. When a node moves, its scheduling ensures that the source and destination correspond appropriately.

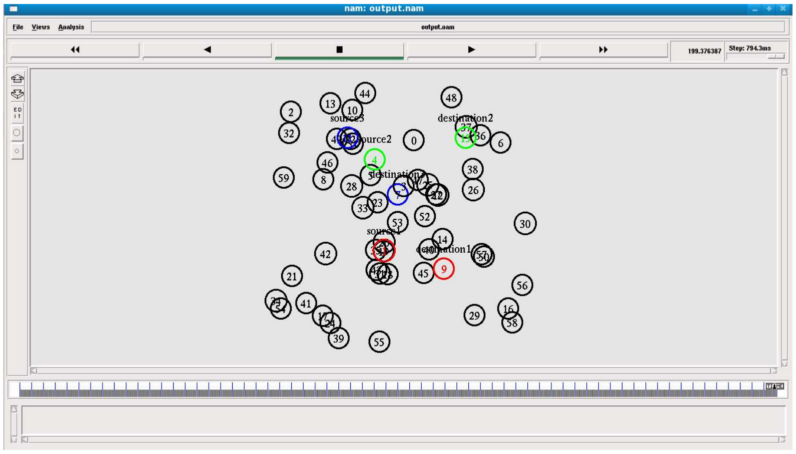


Figure 4. Output of NAM

***Plotting Graph using Gnuplot:***Figure 5illustrates the relationship between throughput and data rate, distinguishing between centralized and distributive systems. The graph is plotted using gnuplot. The data for the graph is obtained through tcl scripting, and the trace file.prique.cc is generated based on the proposed system.

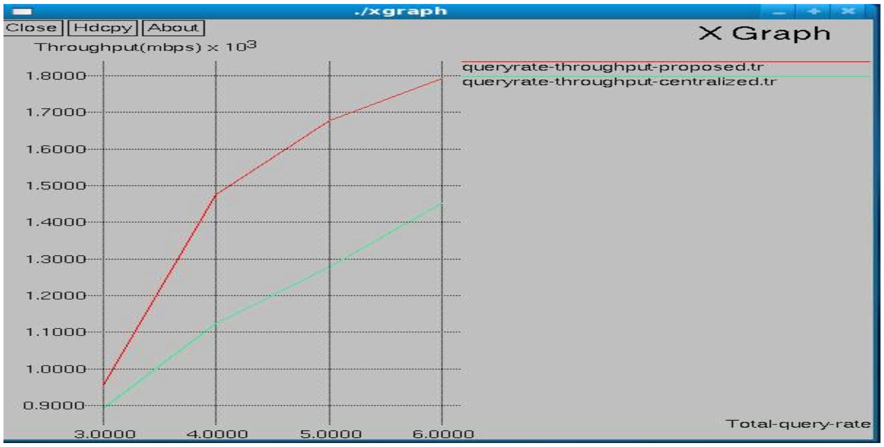


Figure5. Graph comparison throughput vs rate

## 6. CONCLUSIONS

This study presents and assesses an effective distributive algorithm tailored for the dynamic adaptation of both power and rate in the scheduling of links within a spatial-TDMA wireless mesh network. The algorithm's operation revolves around the iterative selection of "winning" links within individual neighborhoods, a process that persists until no further selections are viable. With each iteration, the transmitting end of each remaining link communicates the calculated potential SINR level at its corresponding receiver. This insight serves as the basis for identifying the link with the highest computed SINR, thereby becoming the current "winner."

Throughout each iteration, the already transmitting links establish thresholds on the maximum transmit power levels that can be allocated to accommodate additional link scheduling for the current time slot. In assessing our distributive algorithm's effectiveness, we subject it to a comparison against two recently developed centralized heuristic algorithms. These centralized algorithms have demonstrated an ability to achieve throughput rates closely aligned with those under the optimal scheme.

Through extensive simulations encompassing diverse networking scenarios, our findings highlight that the distributive algorithm achieves a throughput performance within a margin of 5-10% when contrasted with the results achieved by the centralized algorithms. Remarkably, the distributive algorithm offers a significantly lower level of computational complexity in comparison to the centralized strategies.

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