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Power Control in Mac Protocol for Wireless Networks using Hybrid Optimization Techniques

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Abstract

Objectives: To propose power control techniques used in MAC protocol for wireless networks. **Methods/Statistical Analysis**: Energy reductions techniques are essential for wireless networks, as battery powered wireless hosts have limited energy. Hence energy aware techniques with power saving mechanisms are restored to conserve energy of nodes in wireless networks. Power based connectivity is an ad-hoc implements power control mechanisms to enhance network life by improving throughput, cost effective routes and spatial reuse. This study proposes hybrid optimization for "Medium Access Control (MAC)" protocol to implement coordination functions and power control mechanisms. Hybrid optimization is based on "Genetic Algorithm (GA)" and "Gravitational Search Algorithm (GSA)". **Findings:** Experiments with hybrid optimization are compared to GA fuzzy rules and Fuzzy methods. The result reveal that two hop power control with GA fuzzy logic method lowers route discovery time, increases cache replies, minimizes simulation time and end to end delay in contrast to DSR routing and two hop routing protocols. **Application/Improvements:** The new hybrid GA-GSA has a throughput of 8.89% and 1.62% and low end to end delay of 13.66% and 2% compared to Fuzzy and GA based Fuzzy respectively.

Keywords: DSR Routing, Fuzzy Logic, Genetic Algorithm (GA), Gravitational Search Algorithm (GSA), Medium Access Control (MAC)

1. Introduction

Mobile Adhoc Network (MANET) includes arbitrarily moving mobile platforms. Each platform, henceforth called "nodes", have a router with multiple "IP-addressable hosts" and many wireless communications devices. Nodes have wireless transmitters and receivers using antennas[1]. Adhoc network is a dynamic multi hop wireless network established by mobile nodes on a shared wireless channel. Every mobile host performs local broadcasts to identify itself to surrounding hosts. Surrounding hosts are nodes in proximity to transmitting host. Every node acts as router for establishing routes between source and destination[2].

Ad hoc networks are simple to design and easy to install and its advantages include rapid ad-hoc technology development is used in portable computing like laptops, mobile phones to access web services and telephone calls when users are travelling. Self-organizing network development decreases communication cost. Self-healing through continuous re-configuration, scalability, mobility and decentralized administration ensures lower getting-started costs[3]. Its limitations are: intra node cooperation must ensure high performance, throughput dependent system load, nodes for reliability maintenance, and large networks latency/time delay.

In WSN, nodes share a common channel. Hence, MAC sub layer provides access to channels by avoiding collisions. The MAC protocol design goal for WSN is energy efficiency to prolong sensor life. Reasons for wireless communication's unnecessary energy waste are:

- Packet collision: It occurs when nodes fail to listen to medium before transmission of packets due to which

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simultaneously transmitted packets collide. These packets will be retransmitted leading to unnecessary energy waste.

- Control packet overhead: Successful data transmission requires Control packets which are not useful data but are required for transmission.
- Idle listening: Nodes listen to idle channel awaiting data expends energy.
- Over emitting: Occurs when nodes are not prepared for accepting incoming transmission.

For efficient working of WSN, MAC protocols have to address the following requirements:

- Energy efficiency: Generally, sensor nodes are battery powered and extending life is through energy-efficient protocols design.
- Collision avoidance: To reduce collisions of packets.
- Scalability and adaptability: MAC protocol should adapt to network topology changes caused by node movement and wireless transmission's nature.
- Latency: Latency represents packet delay when sent through network. Latency importance in WSN depends on monitoring application.
- Throughput: The data sent reaches destination should be high.
- Fairness: MAC protocol provides fair medium access for active nodes[4].

Many MAC protocols for WSN are planned with the aim of safeguarding energy. Sensor nodes energy usage pattern is application dependent. "Point Coordination Function (PCF)" for centralized protocols and "Distributed Coordination Function (DCF)" for fully distributed protocols are specified by "IEEE 802.11 standard". Both support "Power Saving Mechanisms (PSM)" requiring synchronized network through regular beacon transmissions.

As seen in Figure 1, "Node A announces a buffered packet for B using an ATIM frame. Node B replies by

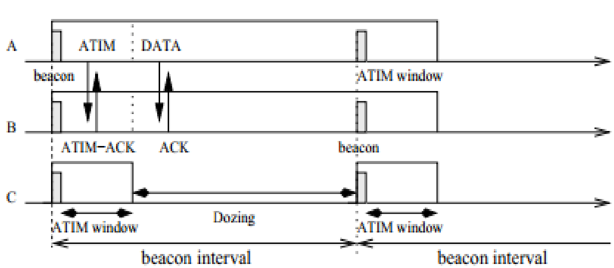

Figure 1. DCF power saving mechanism.

sending an ATIM-ACK, and both A and B are awake during beacon interval when actual data transmission from A to B is finished. As C sends or receives no packet, it dozes after ATIM window".

MAC techniques suggested for WSNs are divided as contention based and schedule based categories. Schedule based protocols avoid overhearing, collisions, and idle listening, through a schedule of specific transmit and listen periods but, have a hard time synchronizing requirements[5]. On the other hand, contention based protocol[6] defers time synchronization requirements, adjusting to topology changes, which are "Carrier Sense Multiple Access (CSMA)" technique protocols having high costs for message collisions, overhearing, and idle listening.

MAC protocols use maximum transmission power to forward "Request-To-Send (RTS)", and "Clear-To-Send (CTS)" packets to save energy and hence determine minimum power needed for data transmission and packet acknowledgement. Power needed for communication is stated in three components: PRxelec, PTxelec, and PTxRad (p). PRxelec is node receiver's power consumption, PTxelec is transmitter electronics' power consumption and PTxRad (p) is power amplifier's power consumption for packet transmission, where p is actual power radiated[7].

Energy consumption during packet transmission through hops from sender node to receiver node with distance d, is given by

$$(d/r)(P_{Rxelec} + P_{Txelec} + cr^{\alpha}) \quad (1)$$

This minimized at

$$r_{crit} = \sqrt[\alpha]{\frac{P_{Rxelec} + P_{Txelec}}{c(\alpha - 1)}} \quad (2)$$

Available power range, to satisfy network connectivity, must be greater than r_{crit}[8,9].

Power saving processes suggests use of 2 varying power states at nodes[10]:

1) Awake: wireless node interface is powered to transmit/receive; node transmits/receives or is idle in this state.
2) Doze: Node's wireless interface is powered down when it does not transmit/receive.

In this paper, a hybrid optimization is proposed to implement coordination functions and power control mechanisms in MAC protocol.

2. Literature Review

Energy efficient cross-layer routing protocol with fuzzy logic based WSN was proposed by Jaradat et al.,[11] where the author aimed at minimizing overall consumed energy and increasing network life. “Nodes remaining battery reserve capacity”, “link quality” and “transmission power within local communication range” are considered to determine next hop node to reach destination.

Fuzzy-logic scheduling for dependable and energy-efficient medical body sensor networks was proposed by Otal et al.,[12] where authors presented a new QOS fuzzy-rule based cross-layer scheduling algorithm. Packet transmissions are scheduled after considering channel quality among the sensors and its medical constraints. The wait time of Sensors and residual battery life are borne in mind during transmission.

Lee et al.,[13] presented a cross layer framework to alleviate problems in MAC and PHY layers. The proposed method control MAC layer contention window size to improve energy efficiency. The contention window size is computed based on competing nodes, and MAC protocol data unit payload length according to PHY layer’s physical channel condition.

Qin et al.,[14] which investigated importance of cross-layer interaction between network layer and lower layers. This study specifically is on wireless network based on “IEEE 802.11e”. The authors highlighted the need of taking into account the cross-layer dependency during design of protocols.

Cross-layer optimization for physical and MAC layers in MANETs with smart antennas was suggested by Guama and Saad[15]. The authors chose two protocols which are inapplicable in mobile environment. The author suggested two control packets, “busy node list” and “overall link state table using adaptive array antennas” to achieve optimal performance. Results showed that the new scheme improved selected MAC protocols performance.

A cross-layer optimization algorithm with MAC layer and routing layer integration meets energy-efficiency requirements was proposed by Liang[16]. The author use communication control packets feedback mechanism in MAC layer to address energy efficiency and reliability issues while designing a “tree-based energy-efficient routing algorithm” to extend network life. Experimental results showed that the new algorithm outperformed other algorithms in that specific environment.

“Cross-Layer Dynamic Source Routing protocol with Load Balancing (CLDSR-LB)” in “Wireless Mesh Networks (WMNs)” were presented by Zhou et al.,[17]. To avoid overloading the nodes, the proposed method uses multi-metric and cross-layer for selection of best route by computing residual available bandwidth and load of MAC layer nodes. To ensure load balancing among MPs, neighbour MP shares traffic when the present one is overloaded while accessing Internet

“MAC-PHY” enhancement for “802.11b WLAN systems” via cross-layering was introduced by Alonso et al.,[18] where the authors analyze the scheme using cross-layer concepts and distributed queues to increase radio channel use. Back-off is eliminated using distributed queues and cross-layer information and data packet transmissions collisions providing stability for high load conditions.

Use of carrier sensing to improve MAC protocol’s energy efficiency in sensor networks was proposed by Nguyen and Ji[19] where the author suggested carrier sensing as a binary signal for the nodes to be aware of the network traffic status. Nodes are in sleep state when network has no data; else nodes operate similar to RMAC’s basic scheme. Experimental results show that the new solution improved energy efficiency while increasing latency slightly.

Cross-layer analysis of the end-to-end delay distribution in WSN was proposed by Wang et al.,[20]. An accurate and comprehensive cross-layer analysis framework, which uses a stochastic queuing model, is developed. This captures WSNs heterogeneity regarding channel quality, transmitting power, queue length, and communication protocols. A case study with “Tiny OS CSMA/CA MAC protocol” shows how developed framework analytically predicts distribution of end-to-end delay. Test bed experiments validate the developed model.

Pourfakhar and Rahmani[21] proposed a “hybrid QOS multicast framework based protocol” for WMNs that used “CMAC neural network model” to predict route/node disconnection probability and control gateways congestion and losses. The protocol combined proactive and reactive multicast routing to remove unwanted delays and reduce control overhead to set up routes among backbone mesh routers. It supported multiple gateways for CMAC prediction based gateway balancing and routing in every node to ensure routes with least miss ratio.

An energy efficient routing protocol with “Adaptive Fuzzy Threshold Energy (AFTE)” for MANETs was proposed by Hiremath and Joshi[22]. MANET’s life is affected by node life. A new on-demand routing based protocol to conserve mobile nodes energy was proposed to increase MANET life. The method was based on residual nodes energy's adaptive fuzzy thresholding and participated in sender to receiver route discovery. Experiments were compared to "Load-Aware Energy Efficient Protocol (LAEE)" protocol proving that AFTE bettered LAEE.

3. Methodology

This study resorts to MAC protocol to ensure coordination functions and power control mechanisms using hybrid fuzzy rules generated with two input variables - link quality and node neighbourhood count and optimal power consumption level as output variable.

The FLC model includes a fuzzyfier, an inference engine and defuzzyfier. The proposed method includes three phases: "Fuzzification" of input variables "battery energy" and "average packet traffic". The input variables: Battery Energy represents the energy level of node and Packet Traffic is average packets that is transmitted by each node. Taking crisp inputs from each variable and determining degree to which inputs belong to appropriate fuzzy sets, through use of linguistic rules. The "inference engine" includes a rule evaluator which takes the fuzzy field inputs and applies them to fuzzy rules and output aggregate or aggregates the fuzzy rule to obtain fuzzy output. The final step is "Defuzzyfication" which translates the fuzzy output variable to one crisp value of sleep time.

"Linguistic variables" used to denote "battery energy" and "packet traffic", within fuzzy domain, are divided into "low, medium and high levels". The outcome to represent MAC parameters is the duty cycle, and specifically sleep period, which are represented with fuzzy variable sleep time. The output fuzzy variable sleep time is divided into seven: "extremely short, very short, short, medium, long, very long and extremely long sets". Block diagram for work is given[23,24]:

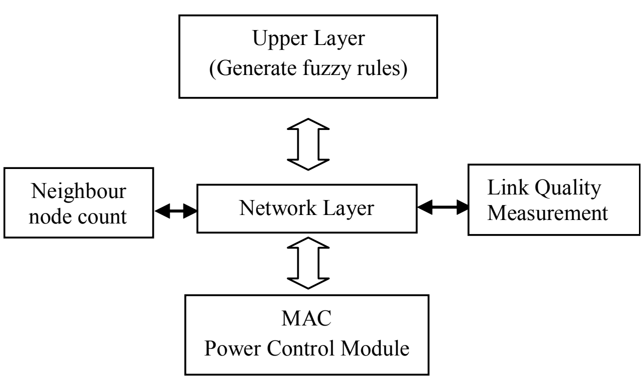

Figure 2. Block diagram of normal approach.

When GAs are used to design fuzzy models it is called Genetic Fuzzy systems (GA-fuzzy)[25,26]. Chromosomes describe GA solutions. Initialization step by clustering, created chromosomes with similar coding, i.e., each element of every chromosome code for same variable. This ensures effective use of crossover operators.

Initialization permits limiting of search space; making optimization problem more efficient. Chromosome representations determine GA structure. With a "population size L", encode parameters of every fuzzy model (solution) in a "chromosome $s_l, l = 1........, L$ as sequence of elements" describing fuzzy sets in rule antecedents followed by rule consequents parameters.

For model M of fuzzy rules, triangular fuzzy sets (given by three parameters), an n-dimensional premise and $n+1$ parameters for every consequent function, a chromosome of $N = M(3n + (n+1))$ length are encoded as

$$s_l, l = (ant_1, ...ant_M, \theta_1 ....., \theta_m) \quad (3)$$

where, "θ contains consequent parameters P_{iq} of rule R_i, and $ant_1 = (a_{il}b_{il}c_{il} ....a_{in}b_{in}c_{in})$ contains parameters of antecedent fuzzy sets".

GA are evolution inspired family of computational model which encodes a set of potential solution to a specific problem on a simple chromosome. These chromosomes are operated on by applying recombination operators to preserve critical information and evolve the chromosomes with better fitness[27]. Broadly, the GA functions as follows:

1. "*Initialization*". A random set of initial population of chromosomes representing the solutions is produced.
2. "*Evaluation:* Fitness values of the chromosomes are evaluated.
3. "*Selection*". Selection helps create copies of solutions with "higher fitness values" by imposing the "survival-of-the-fittest mechanism" on candidate solutions. Common selection procedures used are "stochastic universal selection", "roulette-wheel selection", "tournament selection", and "ranking selection".

$$P_s(i) = f(i) / \Sigma_{j=1}^{n} f(j) \quad (4)$$

where, " $P_s(i), f(i)$ are probabilities of selection and fitness value for ith chromosome" respectively. Parents are selected in pairs[28,29].

4. "*Recombination*". This combines parts of two or more parental solutions in creating new solutions (offspring).

Offspring under recombination is not identical to any parent.

5. *Mutation.* Mutation acts locally and randomly to modify solutions.
6. *Replacement.* The selection, recombination, and mutation created offspring replace original parental population. Many replacement techniques like "elitist replacement, generation-wise replacement and steady-state replacement" methods are used by GAs.
7. Repeat steps 2–6 till terminating condition is met"

Flow chart of the various steps of GA is shown in Figure 3.

"Gravitational Search Algorithm (GSA)" starts with a "set of agents", selected randomly with positions and masses signifying solutions to an issue. As the algorithm iterates, the positions are changed based on values like fitness function, "velocity" and "acceleration" that are updated at every iteration[30]. In a system with N agents, position of *ith* agent is defined as

$$X_i = \left(X_i^1,\ldots,X_i^d \ldots,X_i^n\right) fori = 1,2,\ldots..N \qquad (5)$$

where, "present position of i[th] agent in $x_i^d th$ dimension, and n is search space dimension".

The force acting on mass i from mass j at time t is defined as follows:

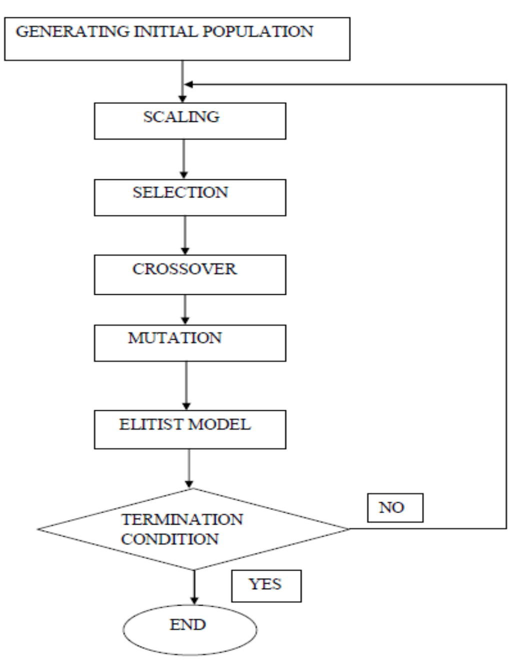

Figure 3. Flowchart of genetic algorithm.

$$F_{ij}^d(t) = G(t)\frac{M_{pi}(t)\times M_{aj}(t)}{R_{ij}(t)+\in}(x_j^d(t)-x_i^d(t)) \qquad (6)$$

where, " M_{aj} and M_{pi} are active and passive gravitational mass of agent j and i, G(t) is gravitational constant, ε is small constant, and $R_{ij}R_{ij}$ (t) is "Euclidian distance between i and j":

$$R_{ij}(t) = \| X_i(t).X_j(t)\| \qquad (7)$$

Total force acting on $mass_i$ in d[th] dimension in time t is given as follows:

$$F_i^d(t) = \sum_{j\in Kbest, j\neq 1}^{N} rand_i F_{ij}^d(t) \qquad (8)$$

where, " $rand_j$ denotes random number [0, 1], K best is set of first K agents with best fitness value". The acceleration for mass i at time t in *dth* dimension is given as follows:

$$a_i^d = \frac{F_i^d(t)}{M_{ii}(t)} \qquad (9)$$

where, " M_{ii} is the inertial mass of i[th] agent"[30].

The next velocity of an agent could be calculated as a fraction of its current velocity added to its acceleration. Position and velocity of agent is calculated as follows:

$$v_d^i(t+1) = rand_i v_i^d(t) + a_i^d(t) \qquad (10)$$

$$x_d^i(t+1) = x_i^d(t) + v_d^i(t+1) \qquad (11)$$

where, $rand_i$ is a uniform random variable in interval [0, 1]".

G is initialized at start of search and is decreased with time for controlling search accuracy:

$$G(t) = G_0 e^{-\alpha\frac{t}{T}} \qquad (12)$$

where, "T is number of iteration, G_0 and α is given constant".

Gravitational mass and inertial mass are updated by equations as follows:

$$M_{ai} = M_{pi} = M_{ii} = M_i,\ i = 1,\ 2\ldots,\ N \qquad (13)$$

$$m_i(t) = \frac{fit_i(t) - worst(t)}{best(t) - worst(t)} \qquad (14)$$

$$M_i(t) = \frac{m_i(t)}{\sum_{j=1}^{N} m_i(t)} \qquad (15)$$

where, $fit_i(t)$ represent fitness value of agent i at time t, and, *worst(t)* and *best(t)* are given as follows for a minimization problem:

$$best(t) = \min_{j \in (1,\ldots,N)} fit_i(t)$$

$$worst(t) = \max_{j \in (1,\ldots,N)} fit_i(t) \quad (16)$$

3.1 Hybrid Genetic -Gravitational Search (HGGS) Algorithm

Hybrid algorithm HGGS aim to achieve minimum response-time for customers and maximum profit for the grid system by scheduling tasks. HGGS is obtained by incorporating GA and GSA as a local search algorithm creating a new genetic algorithm to reach solutions in less time.

HGGS after generating a first population, solutions are sorted based on fitness. Population currently is ready to apply genetic operations. A two-point crossover operator with randomly selected two points combines chromosomes and generate next generation.

After generation of a new solution, a mutation operator and a probability 0.05 will be applied on it to prevent early congestion. Then, the solution is ready for local search algorithm. HGGS calculates attraction force of K best solutions over other solutions and passes up this computation for others, resulting in keeping current appropriate solutions, absorbing other solutions to them and searching more around best solutions. Value of K is very important and obtained using Roulette Wheel algorithm.

Best local solution in i^{th} solution neighbourhood, is passed to GA to be replaced. After applying local search over generation solution, solution on first position in sorted population is best solution. Finally, HGGS algorithm is terminated after attaining desired conditions and presents best obtained solution[31].

4. Results and Discussion

In this study, MAC protocol is proposed to implement coordination functions and power control mechanisms through hybrid optimization (GA-GSA). Upper network layers generated Fuzzy rules using two input variables like link quality and node neighbourhood count; with optimal power consumption level as an output variable. Experiments with GA fuzzy rules are compared with DSR routing and two hop power control methods. The result reveal that two hop power control with GA fuzzy logic method lowers route discovery time, increases cache replies, minimizes simulation time and end to end delay in contrast to DSR routing and two hop routing protocols. The results obtained are shown in Figures 4 and 5.

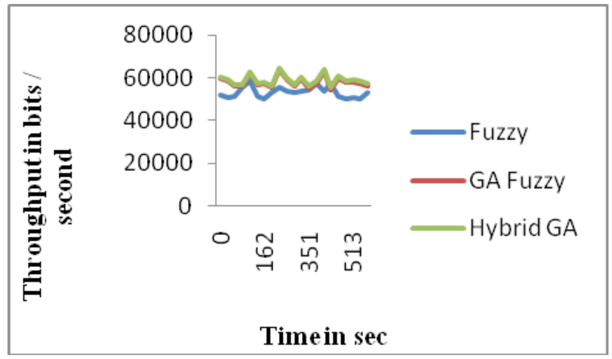

Figure 4. Throughput in bits / second.

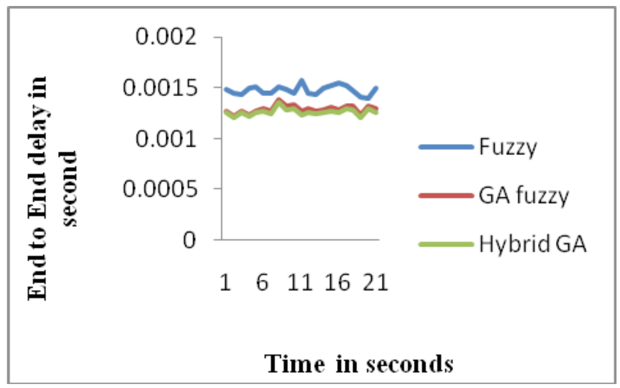

Figure 5. End to end delay in second.

Figure 4 shows the proposed hybrid GA-GSA has high throughput than the other methods proposed.

Figure 5 shows the proposed hybrid GA-GSA has low end to end delay in second than the other methods proposed.

5. Conclusion

Wireless ad-hoc networks are a powerful telecommunication infrastructure exploited to enable general wireless networking connectivity for various applications. Various MAC protocols with different objectives are proposed for WSN. This study used MAC protocol to implement coordination functions and power control mechanisms through hybrid optimization (GA-GSA). Upper network layers generated Fuzzy rules through use of 2 input variables like link quality and node neighbourhood count; with optimal power consumption as output variable. Experiments with GA fuzzy rules are compared to DSR routing and two hop power control methods. The new hybrid GA-GSA has a throughput of 8.89% and 1.62% and low end to end delay of 13.66% and 2% compared to Fuzzy and GA based Fuzzy respectively.

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