Multipath Routing Protocol: For Wireless Ad-hoc Networks Based on Fibonacci

Adnan Ahmad
Sarhad University of Science and Technology, Peshawar, Pakistan
itsme.adnanahmad@gmail.com

Noor Mast
Institute of Computing, Kohat University of Science and Technology, Kohat, Pakistan
noor.mast@kust.edu.pk

Faten Khalid Karim
Department of Computer Sciences, College of Computer and Information Sciences, Princess Nourah bint Abdulrahman University, Saudi Arabia
fkdiaaldin@pnu.edu.sa

Fasee Ullah
Department of Computer and Information Sciences, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, Malaysia
fasee.ullah@utp.edu.my

Carolina Del-Valle-Soto
Facultad de Ingeniería, Universidad Panamericana, Mexico
cvalle@up.edu.mx

Mohamad Khairi Ishak
Department of Computer Engineering, College of Computing and Informatics, University of Sharjah, United Arab Emirates
mishak@sharjah.ac.ae

Samih M. Mostafa
Computer Science Department, Faculty of Computers and Information, South Valley University, Egypt
samih_montser@sci.svu.edu.eg

Jose Varela-Aldas
Centro de Investigación MIST, Facultad de Ingenierías, Universidad Tecnológica Indoamérica, Ecuador
josevarela@uti.edu.ec

Abstract: *A WANET, which stands for Wireless Ad hoc Network, is a temporary network in which nodes are connected to each other via wireless links and there is no central management. Due to its adaptive structure, WANET is very useful in situations when quick communication link setup is necessary. On the other hand, Channel Contention (CC), degrades the performance of WANET and is a major contributor to packet drops. To solve the CC problem, this paper proposes a routing protocol called Multipath Channel Contention Based Routing (MCCBR). Using MCCBR, several paths are discovered for data transmission that have minimal contention between the source and destination. Then the packets are distributed over the discovered routes based on the Fibonacci sequence. The process of searching for new paths for transmission is initiated when the number of found paths becomes less than 50%. The proposed routing protocol was tested and verified using NS2 simulator. The performance of MCCBR was evaluated against the Ad hoc On Demand Distance Vector (AODV) and Channel Contention Based Routing (CCBR) protocols. MCCBR outperformed AODV and CCBR in terms of Packet Delivery Ratio (PDR), End-to-End (E2E) delay, and normalized Media Access Control (MAC) overhead.*

Keywords: *Channel contention, CCBR, MCBR, multi-path routing, wireless ad hoc networks.*

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1. Introduction

Wireless communication technology has developed rapidly due to consumer demand for high-quality services. As a result, new technologies have emerged. The emergence of Wireless Ad-hoc Networks (WANETs) can be directly attributed to this growth of wireless technology [47]. A WANET consists of autonomous wireless nodes that do not require pre-existing infrastructure, and all nodes are connected to each other via wireless links without any central management. Figure 1 illustrates a scenario of WANET, where nodes communicate with one another via wireless links. Nodes can be fixed or mobile and serve as hosts and routers in the network the network's topology in such network is very dynamic due to the nodes' movement. In the case of greater mobility, the topological shift will be substantial [1, 4, 19, 41].

Because of their flexible structure, WANETs provide a dynamic and flexible communication infrastructure that is perfect for situations where connections need to be made quickly. Rescue efforts during natural catastrophes like flooding and earthquakes are excellent examples [6, 46]. Because WANETs can swiftly establish communication links between victims, rescuers, and command centres, they are important in situations where traditional communication infrastructures may be damaged. In the same way, WANETs are extremely useful in combat situations where quick deployment and reconfiguration of communication networks are essential to preserving operational efficacy. Because of WANETs' adaptability, military forces may quickly create secure and reliable communication links that provide real-time command and control, data interchange, and coordination in the face of constantly shifting battlefield situations. All things considered, WANETs' innate flexibility and quick deployment capabilities render them invaluable in dire circumstances where prompt communication can be the difference between life and death.

However, one of the technical difficulties that must be overcome to profit from WANETs is the development of an efficient routing protocol. But multi-hop routing faces challenges such as frequent rout failure, congestion, CC and restricted bandwidth [36, 51], and various routing protocols are developed to address these issues. The following are examples of some routing protocols addressing the different problems faced by routing protocols. To address the issues of route failure, a protocol named Adaptive Backup Routing (ABR) is proposed by Lai *et al*. [21] similarly, a mechanism presented in [50] also tries to reduce link failure. A routing protocol presented in [40], identifies the destination node's location and selects the most feasible relay node. On the other hand, protocols like [22, 35] are designed to utilize the bandwidth efficiently. Mobile devices also have power issues; therefore, as presented in [12], some routing protocols are intended to minimize power consumption. Moreover, a protocol presented in [52] is a secure and Quality of Service (QoS)-aware routing mechanism, and the protocol named Trustworthiness-based Quality of Service (TQOS) routing [54] also addresses the issue of QoS.

Figure 1. A scenario of WANET.

Furthermore, several protocols like [2, 5, 14, 31, 48] were proposed to address the congestion issue. When the network is overloaded, it is said to be congested, and packets are lost because of buffer overflow. Congestion is one of the primary causes of dropped packets in wired networks. However, in WANET, nodes face CC due to the shared medium, resulting in dropped packets. When a packet is lost, the MAC layer signals to the network layer that the route to the destination has been disrupted. As a result, the route recovery process initiated may be without any need [11]. It is reported in [13] that CC losses are dominant compared to congestion losses. That is, congestion (buffer overflow) is very rare in WANET. Thus, designing a routing protocol must consider the CC problem.

Moreover, shortest-path routing is the foundation of most routing protocols. As a result, nodes positioned around the center carry more traffic than nodes set near the network's edges [26]. Therefore, nodes located around the middle of the network experience more CC and cause a waste of resources. In addition, a high volume of traffic might drain node capabilities, including power, processing speed, and available bandwidth. Therefore, there may be better solutions than shortest-path routing techniques, and multipath routing techniques are the most efficient means of addressing the problems caused by shortest-path routing protocols. Because of this, this work aims to develop a multipath channel contention-based routing technique for WANET.

This work aims to extend our previous single-path channel contention-based routing protocol, which was presented in [28]. The extended version is called the Multipath Channel Contention-Based Routing (MCCBR) protocol. The MCCBR protocol proposes to select at most six least contention-based paths, in case more paths are discovered. After discovering the routes, the source node uses the Fibonacci sequence to send the number of packets on these routes. More packets will be transmitted through the least-contended path.

The remaining sections of the article are organized as follows. The related work is discussed in section 2. The medium access method used by the IEEE 802.11 MAC protocol is discussed in section 3. In section 4, we describe the proposed mechanism. The simulation results are presented in section 5, and the study is wrapped up in section 6

2. Related Work

The research community has made an intense effort to develop single and multi-path routing protocols to improve route availability between the endpoints in WANETs. In this section, we present some of the most relevant mechanisms. Notably, Reka *et al*. proposed an adaptive, congestion-aware routing mechanism called Quantum Self-Attention-based Triple Pseudo Siamese Network (QSA-TPSN) [39], it detects congestion using a deep learning architecture and selects less-loaded paths. The mechanism increases the Packet Delivery Ratio (PDR) and reduces end-to-end delay under Havey traffic. While, Legesse et al. proposed a mechanism called Energy Aware Stable Path Ad hoc On-Demand Distance Vector (EASP-AODV) [24], which incorporates residual energy and signal strength to improve route decision. Avoiding weak and unstable links reduces retransmissions and collisions. Moreover, the efficiency and reliability of Mobile Ad-hoc Networks (MANETs) often decreases due to two primary challenges: energy consumption and load balancing, therefore, a routing protocol called Hybris-E2 [20] is designed to address these challenges. This mechanism integrating a hybrid clustering approach with Dynamic Power Control (DPC) and Adaptive Traffic Shaping (ATS). Simulation is carried out in NS3 and achieved 95% PDR. Where a multipath routing protocol is presented by Jaishankar *et al*. [17] called hybrid clustering approach for MANETs. The protocol employs a hybrid Seagull-Mutual Fly Optimization Algorithm (SG-MFOA) to select energy-efficient cluster heads and integrates cross-layer metrics (link quality, delay, bandwidth) to establish multiple stable routes. By combining clustering with multipath routing, it improves packet delivery ratio, delay, and energy efficiency compared to conventional MANET protocols. A scheme called Enhanced-AntT-AODV is one of these mechanisms introduced in [42]. The various parameters used to select the best route are residual energy, hop-count, and signal strength. For a node to be classified as an intermediary node, it must possess a predefined amount of remaining energy; otherwise, it will not be regarded as an intermediary node. Similarly, a node to be considered a next hop, its signal strength should not be less than the predefined thresholds. Therefore, two thresholds are used in the suggested mechanism, i.e., SINGAL_THR and RE_THR. A node will not be regarded as an intermediate node if its signal strength or residual energy is less than SINGAL_THT or RE_THR, respectively. The source node uses the Route Request Packet (REQ-ANT) to broadcast over the network to discover the path. It then gathers data about the path, including its length, end-to-end reliability, congestion, and node residual energy. The destination determines a route's pheromone count after receiving the REQ-ANT packet. Following a predetermined amount of time to receive REQ_ANT via every path, the destination node chooses the path with the largest number of pheromones and forwards the Route Reply packet (REP_ANT) to the subsequent hop to get in contact with the REQ_ANT originator. As a result, a path will be built connecting the source and destination. For congestion and contention control, a scheme is presented in [34] to distribute traffic among nodes based on their queue length, network occupancy, link quality, and QoS level of the traffic flows. The delay is chosen to display both the nodes' forwarding quality and the QoS level of the traffic flows. The delay computation additionally indicates the nodes' queue length and network occupancy level. The essential elements of the suggested algorithm can be summed up as follows:

1. To show the traffic flow's QoS level, a labelling technique is suggested.
2. To determine the network nodes' forwarding quality, the routing metric is computed.
3. The routing metric is used to choose and rank the CS members.

CrossA few cross-layer techniques are used to enhance the suggested algorithm's performance, including dynamic retry threshold and MAC-queue-aware packet retransmission.

The routing protocol named MCLMR (Mobility, Contention Window, and Link Quality-aware Multipath Routing) introduced in [47] is another contribution to this field. By considering mobility, Contention Window (CW), and link quality parameters, this protocol selects the best path. In addition, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method is used in the suggested strategy. The A-CAFDSP (Adaptive-Congestion Aware Fibonacci Sequence-based Data Scheduling Policy) technique presented in [44], chooses effective paths for concurrent transmissions by taking the quality of the paths into account. Moreover, congestion-related loss is an essential metric for route selection in this mechanism since it demonstrates the availability of resources. Additionally, channel losses are taken into consideration as a factor in selecting a route. The Round-Trip Times (RTT) of the RREQ and RREP packets are used to determine the priority of each path after evaluating the best available paths. The data transmission is then initiated. Paths are continuously checked during transmission to rank them based on the degree of congestion. Another load balancing approach known as CBMLB (Channel Busyness Based Multipath Load Balancing Routing Protocol) is introduced in [3] to prevent congestion and reduce the load on the central nodes. This protocol employs a high channel busyness ratio as a criterion to distribute the traffic on the alternative paths, which is an improvement over Ad-hoc On-Demand Multipath Distance Vector Protocol (AOMDV) to route packets towards their destination, it finds the least congested and disjoint paths. The Queue-Based Multipath Load Balancing Routing Protocol (QMLB) is also a load-balancing protocol that is proposed in [32], it finds several disjoint paths towards the destination. This mechanism uses the minimum queue length to find the best route. First, the protocol discovers the minimum queue length for each path. All the routes are sorted according to the minimum queue length of the path, and then transmit the data.

Dynamic Load-Aware Routing (DLAR) [23] protocols is designed to tackle congestion in WANET. The quantity of buffered packets at each intermediary node is used to identify the least congested path. Throughout the ongoing data session, the destination node keeps track of the route's congestion level. The destination node starts selecting a new path if congestion is observed. Congestion Adaptive Routing (CRP) [48], developed by Tran and Raghavendra, periodically checks the ratio of packet volume to buffer size to ascertain whether or not congestion exists. A node alerts its preceding node if it is about to get overloaded. After receiving this notification, the node searches for a bypass route to avoid the congested node. If a node doesn't want to participate in path selection, it must throw away the RREQ packet. Dynamic Congestion Detection and control Routing (DCDR) [43] employs the Average Queue Length (AQL) to identify congestion at the node level. If the AQL and the instantaneous queue of a node are both below their respective thresholds, then the node is considered safe. However, suppose the AQL is more than the minimum and less than the maximum threshold; in that case, the node is anticipated to be congested, and the procedure for choosing an alternative route is initiated. The node is said to be overloaded, and its neighbors are notified if the instantaneous queue size exceeds the maximum threshold. Neighbour nodes try to find other ways to get to their destination to avoid bottlenecks. The Congestion-Aware Routing Protocol (CARP) [30] uses weight measures based on data rate, queuing delay, connection state, and MAC overhead to evaluate the severity of congestion. Then the shortest cumulative weighted sum is used to select the path when multiple RREQ packets arrive at the destination node.

A routing protocol for MANETs is suggested in [10] and named the Congestion Aware Routing Protocol for MANET (CARM) in [10] to deal with congestion. To compute Weighted Channel Delay (WCD), the CARM utilizes the transmission rate, MAC overhead and buffer latency. Moreover, CARM uses the Effective Link Data Rate Category (ELDC) method to cope with the Mismatched Data Rate Problem (MDRP). The ELDC value of a link must be greater than or equal to the value entered in the RREQ packet so that intermediate nodes forward the RREQ on that link.

The Ant-based Congestion Adaptive Multipath routing Protocol (Ant-CAMP) [38] was proposed to locate a path without congestion. Once the queue size rises above a predetermined threshold at any node, the sender is alerted about the crowd. When the sender receives the congestion alert, it begins sending data via the best available path or repeats the route selection process. The multipath routing protocol called Multiple Node-Disjoint Paths Protocol (MNDP) [15] also deals with network congestion. The source then sorts these various possible routes based on total hop count. More weight is given to the shortest route. Therefore, if there are two paths, the higher priority path will carry 66.67 percent of the traffic, while the lower priority path will carry 33.33 percent. The Fibonacci Multipath Load Balancing (FMLB) [46] protocol identifies multi-routes. Assuming a source node identifies K routes using FMLB, they are placed in ascending order based on hop count. Then each path is assigned a weight in the following way.

Fibonacci (K), Fibonacci (K-1), ... Fibonacci (2), Fibonacci (1) the weight of each route determines how many packets will be transmitted upon this path. Like FMLB, the Congestion-Aware FMLB [31] protocol also uses multipath routing. However, it utilizes round-trip time instead of hop counts to set the priority of a route, whereas FMLB uses the number of hop counts.

To alleviate congestion in MANET, the Multipath Load Balancing method for Congestion Control (MLBCC) is presented in [26]. This mechanism tracks the number of incoming and outgoing packets for a predefined interval, then decides the congestion level. While selecting the gateway node, the cost of the links and the paths leading there are also considered. If data volume over a given path exceeds a certain threshold, it is routed through a gateway.

In [2], to enhance Dynamic Source Routing (DSR) [18], a method has been proposed by Ali and Khan. It finds several routes between source and destination and then chooses the best one. A composite metric that considers energy and load are used for route selection. If a node's power falls below a predetermined threshold, it is forbidden from participating in the route selection process. The path will be less crowded or burdened with a minimum cost value. Congestion control is also the goal of the protocols discussed in [7, 29, 33, 49]. In tabular form, the related work is shown in Table 1. The user interested in routing with using fuzzy logic or reinforcement learning may read the paper such as [9, 45].

Table 1. A tabular overview of the related work.

Proposed mechanism	Parameters	Traffic distribution	Issue to address	Compared with	Proposed in	Simulator
QSA-TPSN [39]	Congestion score, residual energy, path length; network traffic load	Single path	Congestion indirectly reducing contention	AODV, DSR, OLSR	2025	NS3
EASP-AODV [24]	Residual energy of nodes, Signal strength and hop count	Single path	Energy depletion and route instability (leading to retransmissions, collisions, contention)	AODV and EAPS-AODV	2025	NS2
Hybris-E2 E2 [20]	Residual energy, cluster head load, transmit power level, traffic shaping ratio	Multipath	Energy consumption+load imbalance (leading to congested relays)	EAODV	2025	NS3
SG-MFOA hybrid clustering [17]	Residual energy, link quality, delay, bandwidth availability	Multipath	Energy efficiency, congestion, and link instability	AODV, DSR	2024	NS2
QoS-aware opportunistic routing [34]	The backlogged traffic, the traffic flows' Quality of Service (QoS) level, and the channel occupancy rate.	Single path	Congestion and contention avoidance	D-ORCD [5] and BORA [55]	2023	NS2
Enhanced-Ant-AODV [42]	Signal strength metric, residual energy metric and hop-count metric	Single path	To improve quality of service	AODV, DSR and Enhanced-Ant-DSR [8]	2021	NS2
MCLMR [47]	Mobility, Contention Window (CW), and link quality	Multipath	Mobility, channel and contention	MP-OLSR [53]	2020	Not specified
A-CAFDSP	Buffer-overflow and channel. induced losses	Multipath	Abrupt data scheduling policy	MNDP, FMLB, CA-FMLB, and DSR	2020	NS2
CBMLB	Channel busyness ratio	Multipath	Load balancing	AODV, AOMDV and QMLB	2019	NS2
Power and load-aware routing scheme [2] to enhance DSR	Estimated lifetime	Multipath	Extending the operational lifetime of nodes and network.	DSR	2018	NS2

Proposed mechanism	Parameters	Traffic distribution	Issue to address	Compared with	Proposed in	Simulator
MLBCC is presented in [26].	Arrival rate and an outgoing rate of packets	Multipath	load balancing and congestion control	AOMDV [27], SBMRP [25] and FMLB	2017	NS2
QMLB	Queue length	Multipath	Load balancing	FMLB, and AODV	2017	GloMoSim
Congestion-aware FMLB [31]	Round-trip time	Multipath	Congestion	AODV	2015	GloMoSim
FMLB [46]	Based on hop count	Multipath	Load balancing to reduce congestion	AODV	2014	GloMoSim
MNDP [15]	Based on hop count	Multipath	Reduce Congestion and E2E delay	AODV	2012	GloMoSim
The Ant-CAMP [38]	Weighted Moving Average (EWMA) of the queue	Multipath	Congestion and reduce E2E delay	AOMDV	2011	NS2
CARP [30]	Data rate, queuing delay, link quality and MAC overhead	Single path	To handle congestion	AOMDV	2009	NS2
DLAR [23]	Number of buffered packets and E2E delay	Single path	Congestion and load balancing	DSR	2001	GloMoSim
DCDR [43]	The average queue length at the node level	Single path	Congestion	EDOCR, EDCSCAODV, EDAODV and AODV	2013	NS2
CRP [48]	Occupancy of link layer buffer	Primary and bypass route.	Congestion to reduce packet delay and loss	AODV, DSR	2006	NS2
CARM [10]	Data-rate, MAC overhead, and buffer delay	Single path	Congestion	DSR	2007	NS2

2.1. Comparison of MCCBR with other Fibonacci-Based Routing Protocols

The existing Fibonacci-based load balancing schemes FMLB [46] and CA-FMLB [31] focus on hop-count or RTT for path ranking, respectively. In contrast, MCCBR fundamentally differs in the following aspects, where Table 2 provides a summary of these aspects:

Table 2. Comparison of MCCBR with FMLB and CA-FMLB.

Feature	FMLB	CA-FMLB	MCCBR
Primary metric	Hop-count	RTT, congestion	Channel Contention (CC)
Weighting scheme	Fibonacci (hop-based)	Fibonacci (RTT-based)	Fibonacci (CC-based)
Route maintenance	Static	Limited adaptive	Dynamic (50% threshold)
MAC integration	No	Partial	Yes (CCF/NC in RREQ)

- Selection metric: MCCBR uses a Channel-Contention (CC) metric computed at each node as a Weighted Moving Average (WMA) of transmission attempts, which is propagated during route discovery via RREQ messages using the CC Factor (CCF) and Node Contention (NC) fields. This makes MCCBR explicitly contention-aware, unlike FMLB/CA-FMLB which rely on hop-count or RTT.
- Path selection policy: Unlike FMLB, which assigns Fibonacci weights based on hop count or RTT ranking, MCCBR first identifies up to six routes with the lowest channel Contention Cost (CC). It then applies Fibonacci weights to these selected routes. In this way, MCCBR gives higher priority to minimizing network contention rather than relying only on shortest-path or latency-based metrics.
- Adaptivity/Route maintenance: MCCBR incorporates a dynamic route-availability threshold (50%) that triggers route rediscovery when the number of available paths drops below half. This adaptive mechanism is absent in FMLB/CA-FMLB.
- Integration of MAC information: MCCBR derives a contention metric from the behavior of IEEE 802.11 MAC protocol and uses this metrics in route discovery process. This feature is not present in Fibonacci-based load balancing schemes (FMLB and CA-FMLB).

3. Accessing Medium in IEEE 802.11-Based Network

In the IEEE 802.11 MAC protocol [16], Distributed Coordination Function (DCF) is the primary method to access the medium. Since controlling how devices share access to the communication medium is one of the major issues in wireless communication, efficient techniques are needed to manage access and prevent collisions. Therefore, DCF employs a technique named Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) to allow access to the share medium by all the relevant nodes. Using the CSMA/CA method, a node checks whether the medium is busy before sending data. If it is busy, the node waits for a short period of time, called the Distributed Interframe Space (DIFS), before sending data. To ensure that the packet was received without collision, the receiver provides an ACKnowledgement (ACK). If there is no ACK from the receiver, retry the frame transmission. If the number of attempts to transmit the frame exceeds a predefined number, the frame is dropped.

The backoff algorithm is initiated after each unsuccessful transmission to avoid a collision. The backoff algorithm's CW is incremented each time, but its value will not exceed the maximum CW. In the case of successful transmission, the CW is returned to its initial value.

To prevent collision between frames, DCF has another mechanism known as the virtual carrier sensing mechanism, which employs two types of control packets called "Request to Send (RTS)" and "Clear to Send (CTS)."

In virtual carrier sensing mechanism, a node sends out an RTS frame before sending data. The RTS frame contains the IDs of the source and destination nodes and a duration field. The duration field stores the amount of time equal to three Short Inter Frame Space (SIFS) plus the time needed to send a data and management frames, a CTS frame, and one ACK frame. In its reply, the destination node will send a CTS frame. The duration field of a CTS frame contains the total amount of time it takes to send data and management frames, plus an ACK frame and two SIFS. When the source node receives a CTS, it delivers data after a SIFS. Every other node will update its Network Allocation Vector (NAV) after receiving RTS/CTS. A node can find out how long the medium will be in use by consulting the NAV. This method is depicted in Figure 2.

If the RTS is delivered, but no CTS is received, either the medium is busy, or a collision has occurred. In contrast, the absence of an ACK following data delivery indicates a transmission failure. After a given amount of time, known as the Backoff time, the retransmission process will be initiated, and the retry counter will be incremented.

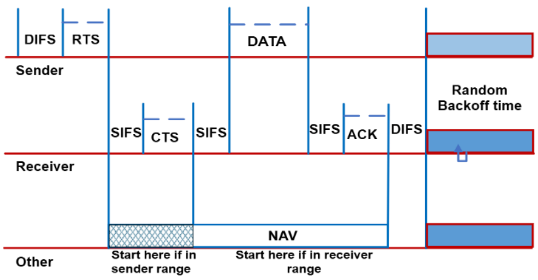

Figure 2. Medium access and data transmission using IEEE 802.11 MAC protocol.

4. Proposed Multi-Path Routing Protocol

MCCBR operates in two main phases:

1) Contention-aware route discovery.
2) Fibonacci-based multipath distribution.

The key innovation lies in the use of a CCF that is computed and propagated during Route Request (RREQ) flooding. The proposed mechanism was evaluated under varying network conditions to ensure its reliability. Such as Figure 3 presents the PDR results, which confirm that the proposed mechanism outperformed both AODV and CCBR.

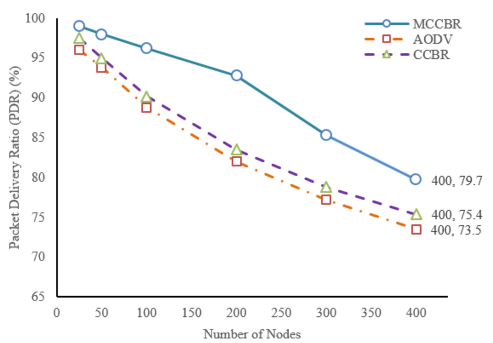

Figure 3. Performance analysis: packet delivery ratio vs network size.

4.1. Channel Contention Computation and RREQ Forwarding

Algorithm (1) counts the number of attempts made for transmission of a packet. A higher number of transmission attempts means higher channel contention, whereas a lower number of attempts means low contention. Instead of making decisions based on a single packet transmission attempt, a WMA is computed to more accurately represent the overall channel contention. The algorithm also determines the number of nodes experiencing high contention. Based on these values, the CCF and Node Count (NC) fields of the RREQ packet are updated accordingly.

Algorithm 1*: Computing channel contention and updating field of RREQ packet at any intermediate node.*

1: Initialize:

- *CCF ← 0 (Channel Contention Factor)*
- *NC ← 0 (Node Contention)*
- *Ratt ← 0 (Transmission attempts)*
- *α = 0.7 (Weighting factor for WMA)*

2: On transmission end (per packet):

- *Ratt = Ratt + 1*

3: On receiving RREQ:

- *Update NC = α * NC + (1-α) * Ratt*
- *Update CCF = CCF + NC*
- *Append CCF and NC to RREQ header*
- *Forward RREQ to neighbors*

4.2. Destination Response and Source Distribution

Sections 4.3-4.5 present the detailed discussion for channel contention estimation, route selection, and traffic distribution over the selected routes. Briefly, Algorithm (2) processes the RREQ packets received from the source during an interval T, which starts upon the arrival of the first packet. The discovered routes are sorted in ascending order of contention, placing the least contended route at the top. If available, at least six routes are selected. The routes are assigned weights from 6 to 1, where the least contended route receives the highest weight.

Algorithm 2*: Destination response and source distribution.*

1: At destination:

- *Start timer T_wait*
- *Collect RREQs from multiple paths*
- *Compute path contention = Sum(CCF along path)*

2: After T_wait expires:

- *Sort paths by contention (ascending)*
- *Select top 6 available routes (least contended)*
- *Return RREP on selected paths (weights: R1w =6, R2w =5, R3w =4, R4w=3, R5w =2, R6w =1 will be assigned at source node)*

3: On route failure at source:

- *Rd = total discovered routes*
- *Rf = failed routes*
- *If (Rd - Rf) < Rd/2, trigger new route discovery*

The first six numbers of the Fibonacci sequence, excluding 0, are: 1, 1, 2, 3, 5, 8. Traffic distribution is performed using these Fibonacci numbers in reverse order. Accordingly, the route with weight 6 is assigned 8 packets, while the remaining routes are assigned 5, 3, 2, 1, and 1 packet, respectively, based on their weights. Moreover, if the number of active routes $(R_d - R_f)$ become less than half of the discovered routes$(R_d/2)$, the source node initiate a new route discovery process.

4.3. Estimation of Channel Contention

The IEEE 802.11 MAC protocol is widely utilized as the de facto standard for accessing medium in WANET. Each node is permitted a certain number of tries to transmit data successfully. In the case of a failure, the packet will be discarded. The maximum attempts for packet transmission mean high *CC* and vice versa. To estimate the *CC* status in the neighbour, a node calculates a WMA of the number of transmissions attempts according to Equation (1).

$$CC_{\mathrm{n}} = (1 - \alpha) \times CC_{(\mathrm{n}-1)} + \alpha \times T\_att, where\ 0 < \alpha < 1 \quad (1)$$

Where CC_n is the current WMA reflects current *CC* and *CC (n-1)* denotes the previous WMA, so it reflects the previous value of *CC* on the node, and *T_att* denotes transmission attempts made by a node. Where α is a weight factor, an appropriate value will be selected in the interval of $(0 \leq \propto \leq 1)$.

If CC_n is the current CC and *CCn-1* is the previous *CC* and let Ratt be the current number of attempts to access the medium by a node, then Algorithm 1 shows how to compute the value of CC and how the fields of the RREQ packet will be updated.

4.4. The Route Selection Process

When a route is required, the source node floods the network with Route Request (RREQ) packets, which allows the MCCBR protocol to generate several paths as needed. The intermediate node adds to its routing table with two entries after receiving the RREQ packet: the source node and the subsequent hop back in the source's direction. These entries are necessary for the RREP packet to be returned to the first node that issued the RREQ request. The related entries in the routing table will be removed if no RREP packet is received in the specified period.

When an intermediate node receives an *RREQ* packet, it should compare its estimated current CC_n with the *CC* value received in the *RREQ* packet from the previous node, denoted as CC_{RREQ}

Then one of the following three cases/scenarios can happen, as illustrated in Equation (2).

$$\left.\begin{array}{ll} Case\ 1. & CC_n < CC_{RREQ} \\ Case\ 2. & CC_n > CC_{RREQ} \\ Case\ 3. & CC_n = CC_{RREQ} \end{array}\right\} \quad (2)$$

- In the first case, the node should only forward the RREQ packet to the next hop.
- In the second scenario, before forwarding the packet, the CC Field (CCF) in the RREQ packet should be updated to reflect the estimated CC value calculated by the corresponding node. Set the Node Count (NC) field to one. The NC field records the highly contended nodes.
- The third scenario shows a situation where the CC value in the RREQ packet matches the CC value at the current node. Therefore, there is more than one highly congested node in the path. When this happens, the NC field should be incremented by one before the packet is sent.

This operation will be performed at each intermediate node. As a result, when the RREQ packet reaches the destination node, it will contain the highest CC value of the route and the number of highly contended nodes.

The destination node will return RREP on the maximum six least contended paths, and the data packets will be transmitted through these paths, as explained in section 4.3. Even though an intermediate node may know the destination path, but it is not allowed to return route replies. The reason is to select a path with new CC information.

Consider a WANET scenario depicted in Figure 4 to provide a concrete example of the route selection process.

- Suppose node S initiates a route discovery process toward node D. So, node S will flood the RREQ packet into the network, where Lable-A is used to denote this RREO packet. Suppose nodes A, G, K, N and R receive this RREQ.
- Then nodes A, G, K, N and R, after updating the values of CCF and NC, will broadcast the RREQ packet to their neighbor, denoted by Label-B.
- Suppose this time, the RREQ packets broadcasted by nodes A, G, K, N and R arrive at nodes B, H, L, O and T, respectively, as illustrated in Figure 4.
- Nodes B, H, L, O, and T will broadcast an updated RREQ packet to their neighbors after making changes required in the CCF and NC fields.
- Like step 4, each intermediate node will broadcast the RREQ packets to their neighbor after making the required updates to the CCF and NC fields until the RREQ packet arrives at destination D (eventually, five packets arrive at the destination node in the given scenario).
- Node D will send RREP through all these routes if these RREQ packets arrive within a pre-defined time interval. The RREQ packets arriving after the specified time interval will be discarded. Since the proposed mechanism recommends a maximum of six routes, the least contended six paths would be selected if more paths were available. The RREP from destination D to source S is depicted in Figure 5.

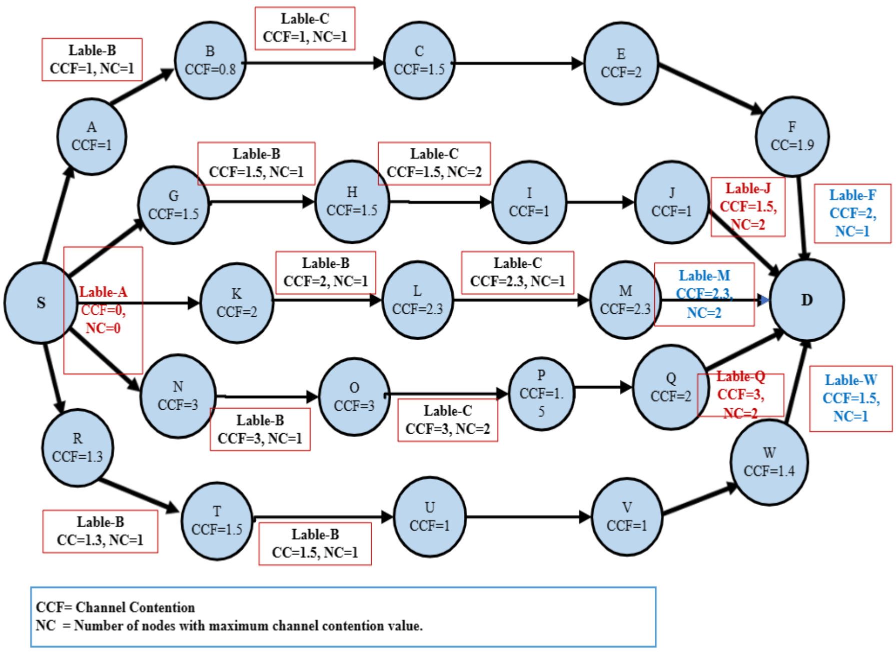

Figure 4. A WANET scenario, where the source broadcasts RREQ to find paths toward the destination.

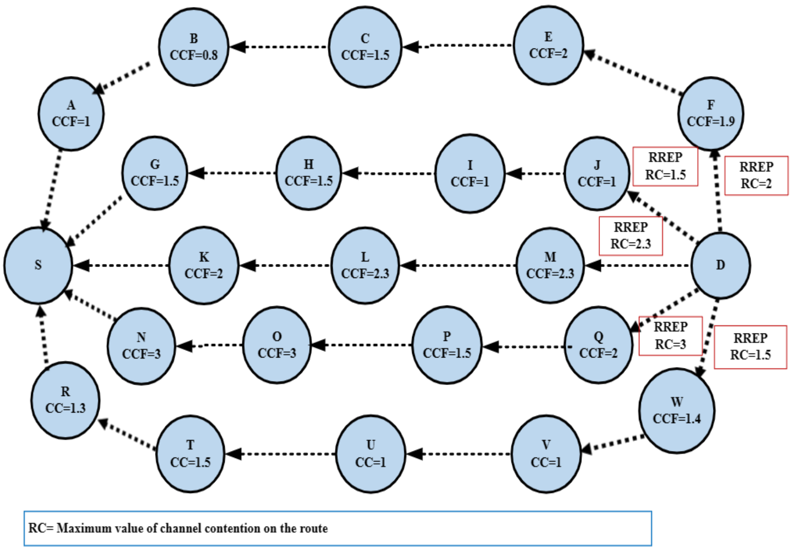

Figure 5. A WANET scenario, where the destination node sends RREP packets to the source node.

4.5. Traffic Distribution on Selected Routes

The number of packets that will be transmitted on a particular path depends on the weight assigned to that path. The Fibonacci sequence is then used to assign the number of packets to each path so that the distribution of packets is in an orderly manner. A less contended path receives more packets than a more contended one, this mechanism prevents packets from being dropped due to contention. Sometimes, the required number of paths will not be available. In such a case, the distribution of packets can be adjusted very easily using the Fibonacci sequence. Equation (3) is the mathematical representation of the Fibonacci sequence.

$$F(0) = 0, F(1) = 1, F(n) = F(n-2) + F(n-1), n \geq 2 \quad (3)$$

Where $F(0)$, $F(1)$ and $F(n)$ represent the first, second and nth numbers of the Fibonacci sequence. If a source node discovers R routes, it will sort them in ascending order based on the observed CC and assign a weight to each route according to the Fibonacci sequence. Then the weight of the first route will be F(R), and the weight of the second route will be F(R-1); similarly, the weights of each route from 3 to 6 will be F(R-2), F(R-3), F(R-4) and F(R-5), respectively.

Table 3. The route weight and the number of packets to be transmitted on each path.

Sorting order on the basis of CC value	Weight		Number of packets to be forwarded on each path
1	F(6)	6	8
2	F(6-1)	5	5
3	F(6-2)	4	3
4	F(6-3)	3	2
5	F(6-4)	2	1
6	F(6-5)	1	1

Suppose that six routes are discovered, that is, R=6, and these routes are arranged in ascending order according to the CC value. Then what will be the weight of each route and how many packets will be sent on each route are shown in Table 3. If the CC value of two paths is the same, the older one will come first in the sequence. Algorithm (2) shows the response of the destination node and the distribution of packets at the source node.

4.6. Modification of RREQ and RREP Packets

The RREQ packet of the proposed mechanism is like that of the AODV packet. However, the proposed method adds two new fields: CCF and NC. These fields are used to convey the maximum CC information along the route towards the destination node. The NC field contains the total number of nodes with the highest CC. The CCF field records the highest value of the CC observed along the route. The modified RREQ packet is illustrated in Figure 6. The fields from 1 to 13 are the original fields of AODV. In addition, the newly added fields are 14 and 15.

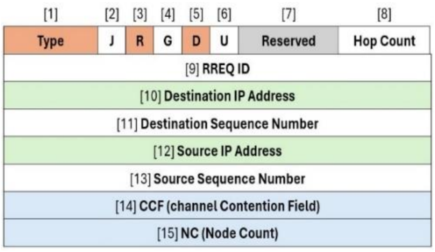

Figure 6. Modified RREQ packet.

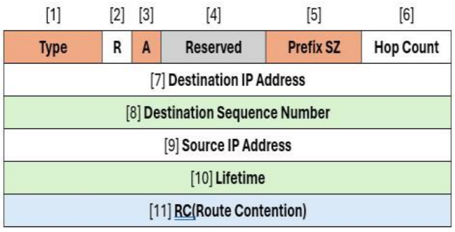

Figure 7. Modified RREP packet.

Moreover, In the RREP packet, a field called Route Contention (RC) has been added to convey the CC value on the selected route to the source node. The modified RREP packet is illustrated in Figure 7. The fields from one to ten are the original fields and the eleventh field in the new one.

5. Simulation and Results

This section presents the comprehensive simulation setup, performance metrics, and results analysis of the proposed MCCBR protocol in comparison with AODV and CCBR protocols.

5.1. Simulation Setup

We implemented MCCBR in NS-2 simulator to evaluate its performance under diverse network conditions. The simulation parameters are summarized in Table 4.

Table 4. Simulation parameters.

Parameter	Values Used
Simulator	NS-2.35
Network size	100, 250, 400 nodes
Area	1500×1500 m, 2000×2000 m, 2500×2500 m
Simulation time	300 seconds
Mobility model	Random Waypoint
Node speed	0, 5, 10, 15, 20 m/s
Traffic type	CBR, Poisson (VBR)
Number of flows	10, 20, 40
Packet size	512 B, 1000 B, 1500 B
MAC protocol	IEEE 802.11
Antenna model	Omnidirectional
Propagation loss	Two-Ray Ground
Number of runs	20 (for statistical significance)

5.2. Performance Metrics

The following metrics were used to evaluate the performance of the proposed routing protocol:

- Packet Delivery Ratio (PDR): ratio of packets successfully delivered to destinations
- End-to-end delay: average time taken for a packet delivery
- Normalized MAC overhead: ratio of MAC control packets to data packets

5.3. Results and Analysis

In this section, the performance of the proposed mechanism is evaluated in term of PDR, average end-to-end delay, and MAC overhead. The results demonstrate the superiority of MCCBR over both CCBR and AODV.

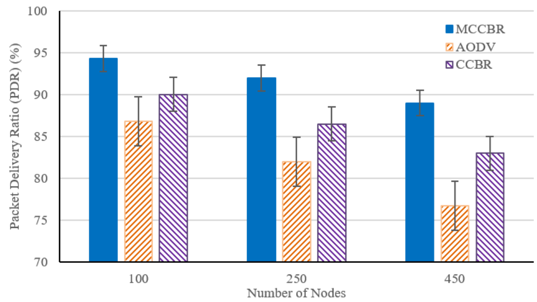

Figure 8. Packet delivery ratio (PDR) comparison for varying node densities.

Figure 8 represents that MCBR has achieved higher PDR across all network densities due to its contention-aware multi path selection mechanism.

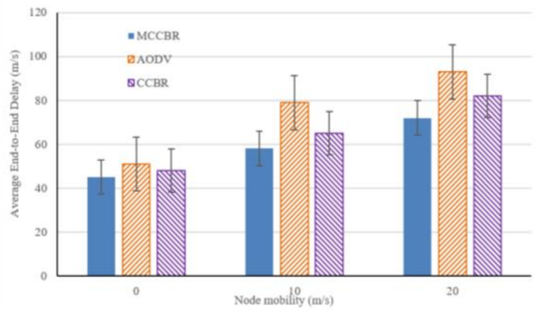

Figure 9. Average end-to-end delay comparison for varying node mobility.

Average end-to-end delay comparison under varying node mobility condition is illustrated in Figure 9. It shows that MCCBR consistently exhibits lower delay than both AODV and CCBR, particularly at higher mobility rates the improvements become more significant, indicating better route stability and reduced retransmission overhead.

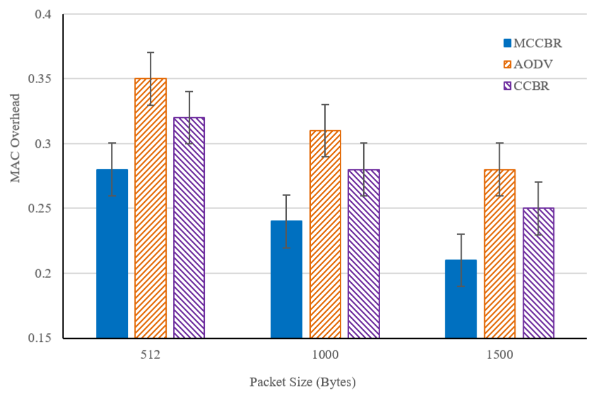

Figure 10. MAC overhead vs packet size.

Figure 10 presents the comparison of MAC overhead for varying packet sizes. The results show that MCCBR consistently achieves lower MAC overhead than both AODV and CCBR. Moreover, the performance gap increases with larger packet sizes due to better channel utilization and reduced control overhead in MCCBR

5.4. Statistical Significance

All results are presented with mean±standard deviation from 20 independent runs. Pairwise t-tests confirm MCCBR's improvements are statistically significant (p<0.05) and results are listed in Table 5

Table 5. Statistical significance (p-values).

Scenario	MCCBR vs AODV	MCCBR vs CCBR
PDR (400 nodes)	$p < 0.001$	$p < 0.01$
Delay (20 m/s)	$p < 0.01$	$p < 0.05$
MAC Overhead	$p < 0.05$	$p < 0.05$

5.5. Discussion

The results demonstrate that MCCBR consistently outperforms both AODV and CCBR across all evaluated scenarios. The contention-aware route selection combined with Fibonacci-based load distribution effectively reduces channel contention, leading to improved PDR, lower delay, and reduced MAC overhead. The protocol shows particular strength in high-density and high-mobility scenarios where channel contention is most severe.

6. Conclusions

In this paper, we have proposed a multipath routing protocol called MCCBR to tackle the problem of CC. To increase PDR and reduce the average E2E delay and Normalized MAC overhead, MCCBR seeks to identify multiple least contended paths between the endpoints. The source node will continue transmission on these paths until the number of discovered routes becomes less than half; the route discovery process will be initiated.

The MCCBR mechanism was implemented using Network Simulator-2 (NS2), and its performance was compared with AODV and CCBR. The evaluation focused on key performance metrics, including PDR, E2E delay, and normalized MAC overhead. Simulation is carried out in various scenarios, considering different node densities (100, 250, and 400 nodes) and packet sizes (512 B, 1000 B, and 1500 B). The results achieved show that MCCBR outperformed both AODV and CCBR across all metrics, showing significant improvements in PDR, E2E delay, and normalized MAC overhead.

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Adnan Ahmad has received a Bachelor's degree in Computer Science from Kohat University of Science and Technology, Pakistan, and an MS degree in Computer Science from Sarhad University of Science and Technology, Pakistan. He is currently working in the IT Department of the Emergency Rescue Service (Rescue-1122), Khyber Pakhtunkhwa, Pakistan. His research interests include Routing Protocols, Load Balancing in Routing, Wireless Networks, and Cloud Computing.

Noor Mast holds a PhD in Computer Science and is serving as a faculty member at the Institute of Computing, Kohat University of Science and Technology (KUST), Pakistan. He is actively engaged in academia and research. His research interests focus on the Design of Routing Protocols, Congestion Control, and Channel Contention Management in Wireless Networks. In addition, he also maintains a keen interest in Machine Learning and its Integration with Emerging Communication Technologies.

Faten Khalid Karim is an assistant professor at the department of computer sciences, College of Computer and Information Sciences, Princess Nourah bint Abdulrahman University, Riyadh Saudi Arabia. She got her PhD degree in Computing and Information Technology from Flinders University in South Australia. Her area of interest includes: Cloud Computing, and Information Technology. She has published several research articles in her field.

Fasee Ullah graduated from Universiti Teknologi Malaysia (UTM), Malaysia, Faculty of computing in 2017. Dr. Fasee has also completed the postdoctoral fellowship from the University of Macau (2019-2021), which is the academic talented program of the Government of Macau. Currently, he is working as Associate Professor at the department of Computer and Information Sciences, Universiti Teknologi PETRONAS, 32610 Seri Iskandar, Perak Darul Ridzuan, Malaysia. He has published many research papers in reputed impact factor journals and conferences. Dr. Fasee is the recipient of the Chancellor Award and the Best Student Award at UTM during his PhD, for his excellent research contributions to wireless communication and health monitoring. His research areas included are Wireless Body Area Network, Wireless Sensor Networks, Cloud Security, Smart Hash Security Designing, Smart Cities, Big data analytics, Machine learning, Deep Learning and Internet of Things. He is currently providing reviewing services to IEEE Transactions on computers, Transactions on Network Science and Engineering, IEEE Transactions on Cloud Computing, IEEE Access, IEEE Sensor Journal, ACM, and International Journal of Distributed Sensor Networks.

Carolina Del-Valle-Soto received the bachelor's degree in Electronics Engineering with a thesis on "Design and construction of a photon counting system" the Master's degree (Hons.) in Science in Electronics Engineering (Telecommunications) with a thesis named "Development of a P2P network with DNS security" and the Ph.D. degree (Hons.) in Information Technology and Communications, with a Doctoral Dissertation titled "Design, Implementation and Comparison of a New Routing Protocol for Wireless Sensor Networks." Currently, she is the Head of the Engineering Computer Academy, Universidad Panamericana, Guadalajara, Mexico. In addition, she directs and coordinates the Master's in Cybersecurity with the Graduate Engineering Department, Universidad Panamericana. She is a Titular D Researcher Professor and she belongs to the National System of Researchers, Level I. She is the author of more than 100 articles indexed in the Scopus citation report.

Mohamad Khairi Ishak received the B.Eng degree in Electrical and Electronics Engineering from the International Islamic University Malaysia (IIUM), Malaysia, the MSc. in Embedded System, from the University of Essex, United Kingdom and PhD from the University of Bristol, United Kingdom. He is a member of IEEE and a registered graduate Engineer with the Board of Engineers Malaysia (BEM). His background includes outstanding teaching experience at the Universiti Sains Malaysia instructing students to stimulate engineering information interest and retention while invigorating classes through the use of new technologies and models. His research interests are Embedded System, Artificial Intelligence, Real-Time Control Communications and Internet of Things (IoT). Emphasis is given towards the Development of Theoretical and Practical Methods which can be practically validated. Recently, significant research effort has been directed towards important industrial issues of embedded networked control systems with AI and IoT.

Samih M. Mostafa received the Bachelor's and M.Sc. degrees in computer science from the Computer Science-Mathematics Department, Faculty of Science, Qena University, in 2004 and 2010, respectively, and the Ph.D. degree in computer science from the Advanced Information Technology Department, Graduate School of Information Technology, Kyushu University, Japan, in 2017. He is currently a fellow with the Academy of Scientific Research and Technology (ASRT), Egypt. His research interests include IoT, Machine Learning and CPU scheduling.

Jose Varela-Aldas received the Master's degree in Control Systems from Escuela Superior Politécnica de Chimborazo, and the Ph.D. degree in Electronic Engineering from the University of Zaragoza. He is an Industrial Engineer with the Universidad Técnica de Ambato. He is currently Director Research and Associate Professor with Universidad Tecnológica Indoamérica, where he is also the research of the MIST Research Center. His research interests include Control Systems, Robotics, the IoT, Machine Learning, and Virtual Reality. In 2023, he was recognized as the Best Young Researcher by IEEE Ecuador. In 2024, he served as the President for the IEEE Ecuador Robotics and Automation Society. In 2025, he founded IEEE PUMABOT, the first battlebot league in Ecuador.