Co-Op RPL: Co-operative IPv6 Routing Protocol for Low-Power and Lossy Networks for IoT

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***Abstract*—Routing protocols have an important part to play in maintaining the interoperability of the components that make up the Internet of Things. To make communication amongst the Internet of Things (IoT) a reality, IETF-ROLL has standardised the routing protocol RPL for IoT networks. We have attempted to yield the advantage of the cooperative nature of nodes to further improve the energy efficiency of low-cost, low-power, low-processing embedded devices. To do this, algorithm Co-Op RPL selectively force nodes to enter sleep mode on a regular basis. We carried out a comprehensive simulation research utilising the Cooja simulator to investigate how a node's cooperative character affects its average routing metric, average power consumption, and average radio duty cycle. According to the simulation results, Co-Op RPL can cut average radio listen ratios by up to 8% and average radio transmission ratios by up to 13% when compared to normal RPL.**

***Keywords*— IoT, Contiki Cooja Simulator, RPL, Energy Efficient, Routing Protocol.**

I. Introduction

IoT is abbreviated as Internet of Things, is a network of interconnected computing electronic devices, embedded devices and things like animal, people, items etc. IoT enables communication amongst these things through an interconnected common platform to exchange data without demanding human-to-machine or human-to-human interaction [17][19]. Low-power features of LLN [16] devices include constrained processor and storage capacities. When used in hostile environments, these limited characteristics generate a variety of problems, especially with respect to networking and communication.

LLNs relay data via many resource-constrained embedded devices, making routing crucial. As per the specification laid by 6LoWPAN, group of people working on Routing Over Low-power and Lossy network (ROLL) standardised a routing protocol by name RPL (IPv6 routing protocol for low-power and lossy networks) for LLNs 18].

To facilitate the communication between machine-to-machine (M2M) and Internet of Things, RPL is seen as a promising contender to support LLNs [20][21][23][26]. To address the challenges of large networks with many nodes communicating over unstable and lossy links (LLNs), RPL was established as a proactive IPv6 distance vector routing protocol.

Even while RPL largely satisfies the requirements of low-power and lossy sensor networks, there are still a few things that need be clarified and improved. Particularly in regard to the minimization of packet exchange among nodes, which improves energy conservation as well as network lifetime, its performance and Quality of Service.

Co-Op RPL is an extension of RPL that we propose in this paper. It allows for co-operative communication among the nodes in the network, which minimises the nodes' active participation in communication all the time. As a result, the nodes' energy is conserved, and the network's performance is improved. Our method uses the potential communication range of the network to choose nodes for inclusion in the cooperative vector and to determine whether or not they are cooperative.

The co-operative vector's nodes are free to operate in either an active or sleeping mode at any given time. The mechanism of the round robin algorithm is used to choose the node from co-operative vector to act as active node. Once the node is selected from the cooperative vector the rest of the nodes are put to sleep for a length of time τ that has been chosen in advance. Now, only active nodes take part in the communication; as a result, Co-Op RPL is efficiently utilising network resources, hence reducing the amount of energy that is consumed.

The following are some of the contributions made by this paper: (i) The suggested Co-Op RPL will be implemented in the Contiki 3.0’s Cooja simulator. (ii) Evaluation of the performance of native RPL and Co-Op RPL with regard to the average amount of energy consumed, the radio duty cycle, and the routing metric.

The remaining part of this paper is structured as described below. In Section II, we conduct a literature review of recent studies and articles that focus on RPL. In the III Section, a comprehensive explanation of Overview of RPL and Co-Op RPL is provided. In the section IV, the findings of the ContikiOS and Cooja simulations relating to the comparison of Co-Op RPL to the standard RPL are reported. The paper is brought to a close in Section V, which also outlines potential future research.

II. Related Work

The Wireless Sensors Network (WSN) is the backbone of the Internet of Things, which refers to the process of connecting devices connected to a WSN to the internet. Memory and power are both in short supply on these devices, which have somewhere around 100 kB of storage space at most. The performance of such networks is largely determined by the operating systems that are used for the networks. Routing in operating systems like these has led to the invention of a protocol called RPL, which ensures that resources are used effectively. RPL is a proactive distance vector source routing protocol that operates on top of the MAC layer and the physical layer of IEEE 802.25.4 networks [1]. RPL was developed by Cisco Systems.

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In this section, some studies that are relevant to this work will be presented. The researches in question are the ones that make use of the Cooja simulator.

The research study [1] have implemented RPL in the Cooja simulator. They have thoroughly analysed the protocol and concluded that RPL has the potential to make a contribution to the development of the Internet of Things since it involves the effective exploitation of available resources. According to the findings, it satisfies all of the requirements for Low Power and Lossy Networks. The outcome of the simulation demonstrated that the objective function MRHOF performs significantly better than OF0 when used as the objective function.

The [2] author also added RPL to the Cooja simulator. The author came to the conclusion that the network topology has no appreciable influence on the energy consumption of the sensor node based on the simulated scenarios. However, when the transmission ratio (Tx and Rx) was altered to fifty percent 50%, there were considerable changes in the amount of energy used. Low transmission ratio is caused by poor link quality between nodes, which in practise means that there are external impediments or disturbances. Author also came to the conclusion that poor transmission ratio had a significant impact on how well the network's sensor nodes performed. Each sensor node had to perform more computations because it was challenging for them to find the best path to their destination. Each sensor node uses more energy the more complex the computation it does.

A research study [10] analysed the differences and similarities between the WSNet simulator [11] and the Cooja simulator [12]. They conducted two experiments to check the performance of the simulator WSNet and Cooja: the first was an experiment to check the capability of sensor nodes in extending the network lifetime by improving the mobile sink performance in WSN. The second experiment compared how effectively the two simulators replicated the capabilities of the WSN. It was noted that the WSNet simulator could simulate mobility on the node sink, whereas the Cooja simulator could simulate Powerline Communication Networks (PLC). Their author concluded that the WSNet is best simulator compared to that of Cooja Simulator.

Paper [13] contributed to the development of the 6LoWPAN, Constraint Application Protocol (CoAP), and ZigBee as a part of their overall body of work. This task was done by carrying out an investigation into the operational efficiency of the stack protocol, which was modelled after the Internet Protocol (IP). The performance measurements included end-to-end delay, throughput, and packet loss in order to evaluate the efficiency of such protocols. Additional results showed that the 6LoWPAN protocol was capable of overcoming the interoperability problem of ZigBee protocol that was previously present in it. This was shown by the fact that it was able to do so. This problem meant that the ZigBee protocol could only effectively connect with sensor nodes that also utilised the ZigBee protocol. The RPL routing protocol is another application that is suitable for the spanning tree technique. Within the context of this protocol, the algorithm was involved in the process of the construction of the tree degree by the nodes that were in a position to recognise their neighbouring nodes. As a result, they serve the function of the load balancer on RPL [13]. Two of the criteria that were utilised in this process were the routing metric and the node rank. They decided to call their system the Minimal Degree- RPL methodology (MD-RPL).

In the course of the research that was carried out by [14], an analysis of the operational capabilities of a number of different RPL routing tree instances was performed. They conducted simulation experiment on low power devices with lossy network condition. The protocol was examined to check its effectiveness based on network parameters like packet delivery ratio (PDR) latency and tree convergence. Author concluded that the performance of the proposed protocol is improved while using a greater number of RPL routing tree instances rather than a single RPL routing tree instance with respect to foresaid parameters.

The study was conducted by [15] to verify the performance of the routing protocol RPL by limiting each nodes' transmission range. This is done because, in the actual situation, it is impossible for each node transmission to have free resistance. The reason behind this is as follows: The performance of RPL was evaluated based on several metrics, including the the amount of delay experienced while delivering the packet, PDR Packet Delivery Ratio, and the energy consumption. Above said three parameters were measured based on the link quality Estimated Transmission Count (ETX), and objective functions such as Objective Function Zero (OF0), and (MRHOF) Minimum Rank with Hysteresis Objective Function

III. Overview of Protocol

A. RPL

Routing protocol RPL makes use of an optimized route to transfer the traffic form sensor nodes towards a destined sink node [2]. RPL is a highly adaptive routing protocol that provides alternative routes in the event that default routes are inaccessible. It is a solution that can be applied to networks with low power and high loss. Making Destination Oriented Directed Acyclic Graphs (DODAGs) is one of the ways in which RPL helps to organise topology formation.

A DAG contains a single destination to where all traffic is rooted. This DAG is included in the DODAG data structure, along with a DODAG root that does not have any outbound edges. The DODAG root is responsible for the tuning of a variety of parameters, including the Trickle timing choices, Path Control Size, Minimum Hop Rank Growth, and the DODAG preference field [2]. Each RPL Instance is implemented by making use of its own one-of-a-kind Objective Function, and a solitary RPL instance may contain numerous DODAGs. The ranks of a node is determined by the precise placements of the node in the network with respect to that of the sink node. This is done in order to create a tree structure. If the node is nearer to sink then its rank improves, while if the node moves away from the sink node its rank gets worse.

The OF is the one responsible for computing ranks. The way in which nodes are chosen and the way in which routes are optimised are both defined by OF in the RPL instance. OF is the one that decides which DODAG nodes will be joined by which other nodes. OF [7] generates an ordered list of the computations performed by the parents as well as the number of peers that serve as parents in that DODAG. The majority of the time, there are two categories of OF. The first of them is known as Objective Function Zero (OF0), and it bases its routing decisions on the total number of hops that must be taken between two different locations. The second kind of objective function is called the Minimal Rank with Hysteresis Objective Function (MRHOF) [24][22], and it is utilised with ETX that possesses additive properties all along a path. In addition to the minimum number of ACK frames that must be sent for a packet broadcast to be considered successful, ETX monitors the usual volume of data frames that are sent.

RPL primarily transfers information using the following four control messages: To begin, there is the DODAG Information Object, also known as the DIO. This object grants the nodes the ability to discover RPL instances which helps in selecting a DODAG parent set. The control message DIS abbreviated as DODAG Information Solicitation is used in the second place to request RPL nodes for the DIO message [2]. DIS stands for DODAG Information Solicitation used by an orphan node in the network to search for DODAG. The third is known as the Destination Advertisement Object (DAO), and Its function is to transmit destination information to the DODAG root in a non-storing mode and upwards towards the sink node in a storing mode so that the sink node can select the proper parent node. A node will send data all the way up to the DODAG root when the non-storing mode is engaged. This is accomplished by the node sending messages recursively to its DIO parents. In the storage mode, a node will send the packets it receives through its DIO parents until it reaches an ancestor via whom the target prefix can be accessed. The fourth type of message is the DAO Acknowledgement, often known as DAO-ACK. DAO parent transmits this type of message as a to a DAO unicast message.

RPL makes use of a trickle timer so that only updates are sent out into the network when there is an inconsistency. This helps to limit the amount of control messages that need to be sent. If a node hears DIO updates from a neighbour that is in a consistent state, then that node's redundancy counter will be incremented. If the number of consistent updates in a given time interval is greater than the redundancy constant, then the node will refrain from sending any updates and will instead double the length of the listen period.

However, if the timer detects an update that is not consistent, it will reset itself and begin delivering DIO messages at a more regular rate. This will ensure that the updates are propagated across the remainder of the network. In order to preserve available energy, the Trickle timer will send fewer control messages when the network is operating normally.

The construction of the DODAG in a given network initially begins at the root node, which is also denoted as sink node in some contexts. The evolution of DODAG is depicted in Fig. 1. Here the root node responsible for dispensing DIO messages to the nodes that are directly linked to it in order to transfer DODAG data. These messages are sent via broadcasting. After receiving the DIO message, the immediate neighbour nodes which are connected to root node, will first process the DIO message, and then it will send the message on to the node that comes after it in the chain. Messages sent via DIO finally made their way to the different other nodes in a manner that was comparable to how the D0DAG system operates.

If the node that is receiving the DI0 message does not belong to any DODAG, then the node will calculate its path overhead depending on the objective function of DIO message of the sending node [10]. It also calculates path overhead it will incur during communication and then decide either to join the D0DAG system or not. If the node receives the DI0 message and corresponding node is already part of the same D0DAG, then it assumes the received DIO message as duplicate one and hence discards the message. When a new node joins the D0DAG, it has to perform calculation to determine the path to reach its respective D0DAG root node. Moreover, the node which has sent the DIO message to this node, now gets promoted to the position of parent of that node in the D0DAG. Following this, the current node determines its own Rank relative to the root node of the D0DAG based on the 0F objective function in the D0DAG, and then it communicates this information to its parent node in the form of the DAO.

If any unknown node has not joined any of the DODAG system and it has not even received any DIO message from any other nodes in the network, then the unknown node itself sends a DIS message to its direct-connected neighbour on a periodic basis. DIS message requests for the DODAG information from the nodes which are directly connected to it. This process continues until the node receives DIO message and joins a DODAG system.

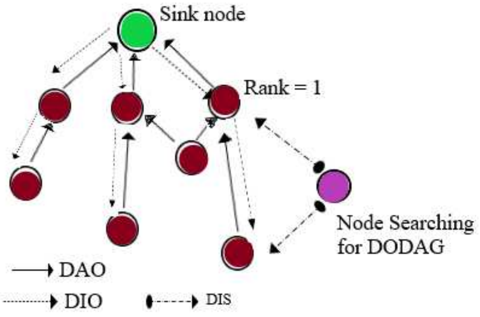

Fig. 1. Construction of DODAG in RPL

B. Co-Op RPL

While routing the packets in IoT network, rather than involving all nodes in communication only a set of nodes are made to actively participate in communication. The primary objective in this context is to lessen the participation of the nodes, which will, in turn, help to preserve the energy of the nodes and, as a result, increases the network's lifespan.

In order to accomplish this, CoOp RPL labels as cooperative any set of nodes that are within the communication range of a packet as shown in Fig. 2. Only one of these sets of cooperative nodes is selected to be active at any given span of time, and the rest of the nodes are put into sleep mode so that they are not alerted to any incoming packets. This ensures that all of the nodes are able to continue functioning normally. On the other hand, they are free to listen in on any other kind of communications that are taking place on the network.

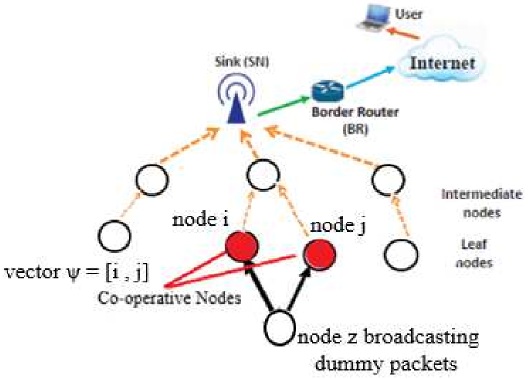

Fig. 2. Architecture of Co-Op RPL routing domain

The concept of active and sleep is combined with the Round Robin algorithm in Co-Op RPL, which allows it to select any one node from a set of cooperative node vectors ψ as the active node. In order to prevent a bottleneck at a specific node, the active node only takes part in the communication for a limited amount of time τ at a stretch of time that has already been determined in advance. Therefore, only the active node in a group of nodes will take part in the process of communicating the various messages.

The cooperative timer of the node is started once it has been selected, and it immediately begins accepting packets. After the packet has been received, a check is performed to determine if it is being examined for the first time. If the answer is yes, the device adds the packet's originator to its neighbour list and only processes the packet if its rank within the DODAG is lower than the rank of the packet's originator. In that case, the packet will be thrown away.

Following the completion of the processing of the packet, the active node will then update its routing metric, which includes its transmission power, receiving power, and residual power, before sending the packet on its way to its destination. Later a node checks its co-operative timer to decide either to continue with the process or to go to sleep mode. Fig. 3 shows how the suggested framework functions in its entirety. The primary focus of Coop RPL is on the efficient utilisation of a node's resources, with the end goal of reducing energy consumption.

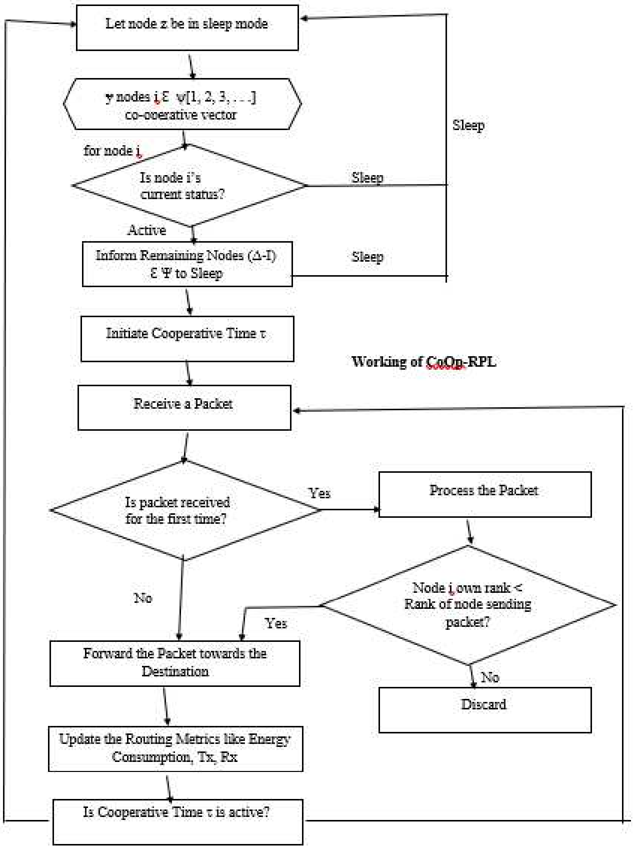

Fig. 3. Workflow of Co-Op RPL

IV. Simulation Results And Discussion

A. Simulation Setup

On Contiki3.0, the Co-Op RPL has been implemented. Emulation presents itself as a very viable alternative for the evaluation of the performance of IoT protocols [3]. It is a great news considering that ensuring reproducibility is a major issue of the networking community. The Co-Op RPL actual code is implemented on emulated Internet of Things devices To do this the built-in Cooja emulator that is included as part of Contiki3.0 is utilized.

Due to the following characteristics, Cooja has established itself as the de facto emulator for testing Internet of Things protocols: 1) In Cooja the simulations are executed at the hardware level, making use of the real hardware characteristics of the emulated nodes; 2) Cooja simulates the behaviour of fine-grained nodes by imitating the processing of the particular instruction set that corresponds to each node; 3) It makes it possible for the code to be executed directly on real motes; and 4) It enables the use of existing network models such like medium interference, link quality, typologies, and radio propagation to evaluate proposed solutions. [25].

For the purpose of this analysis, we will refer to the physical topology of the network as a two-dimensional grid with twenty rows and twenty columns. The trials make use of a topology that has 11 nodes overall, including 10 sensor nodes and 1 sink node, and these nodes are spread out over a region that is 200 metres by 200 metres in size. To ensure that all other nodes in the network are accessible to as many users as possible, the sink node has been positioned in the middle of the network. UDGM model is utilised to simulate the lossy environment due to the fact that a unit disc graph medium model [4] is widely utilised in the most of research literature. For all of the participating nodes, including the sink node, BR, this model is utilised with an interference range of eighty metres and a unified transmission range of sixty metres. The skymote platform is used to implement the proposed algorithm.

In addition to a 25Okbps, 2.4GHz, IEEE 8O2.15.4 Chipcon Wireless Transceiver, the Skymote platform features a microcontroller with the model number MSP430 F1611, a radio Chipcon with the model number CC2420. The Skymote also features a random access memory (RAM) of 16 kilobytes and a flash memory of 48 kilobytes. As the default transport layer protocol, the User Datagram Protocol (UDP), is used. UDP protocol does not involve in retransmission of packets and hence less overhead. A routing table is used by the routing protocol. This routing table contains a detailed information about the path cost associated with the destination node, next-hop node info and an expiry timer, for which co-operative node should be active. To make things easier to compare, we decided to keep the active time of a cooperative node at 64 milliseconds. Yet, one is able to alter it to 128 ms or 256 ms and then examine how it behaves.

In this simulation, the MAC layer is represented by the IEEE 8O2.15.4 protocol, and the beaconless mode is realised through the utilisation of unslotted CSMA/CA. A radio duty cycle (RDC) protocol is implemented with the help of the ContikiMAC protocol [8]. Sending the nodes into sleep mode for the majority of the time is one of the many optimizations that are implemented by Co-Op RPL in order to lower the amount of energy that is used. It is necessary for one of the nodes in a network of cooperative nodes to wake up on a regular basis in order to actively participate in communication and search for prospective transmissions. Table I contains an outline of the simulation's various parameters. The cooperative behavior of the node is best exploited here in order to prevent a node's energy from being wasted, and there by to improve the lifetime of a network.

TABLE I. Cooja Simulation Parameters

Settings	**Value**
Platform	Contiki/ Cooja
Bandwidth	1 Mbps
Emulated Mote	Sky Mote
Radio Environment	UDGM
Transmission range	Transmission range:60m Interference range : 80m (50 nJ/bit)
Network Layer Protocol	RPL & 6LoWPAN & uIPv6
Transport Layer Protocol	User Datagram Protocol
MAC protocol	IEEE 802.11
Simulation Period	30 min
Intensity of Traffic	1, 2, 3 and 4 PPM per node which is variable[5]
MAC and PHY	CSMA/CA and IEEE 802.15.4[27]
Topology	Regular 2D-Grid Topology
Network area	200 x 200 m^2
Number of sensor nodes	10 Sensor Nodes + 1 Sink Node
Location of sink node	At center
Data Packets' size	500 B
Packer headers' size	20 B
Size of Broadcast packet	16 B
Co-operative active time τ	64 ms, 128 ms, 256 ms

B. Simulation Results

In order to better grasp the functionality of CoOp-RPL, we carried out extensive simulations in which we compared it to conventional RPL. We experimented simulation by altering the number of DAG nodes and the packet transmission rate; and observed what effect these changes had on network parameters like average power consumption, the average routing metric, and average radio duty cycle.

Fig. 4. shows the average power consumption by node both in CoOp RPL and conventional RPL. Through the usage of Powertrace's plugin, the Cooja simulator keeps track of how much energy is being consumed by the sensor node. Among the parameters that were measured were the energy used by radio listen, the energy used by radio transmit, the energy used by Low Power Mode (LPM), and the energy used by the central processing unit (CPU).

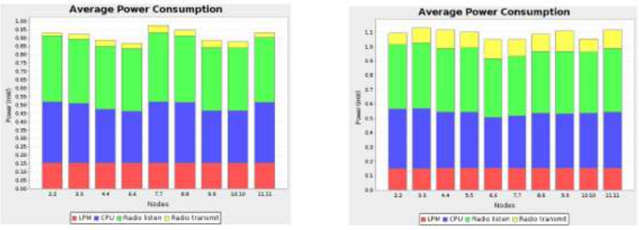

Fig. 4. Average Power Consumption by nodes in CoOp-RPL & RPL

According to the results of the tests conducted on CPU Power parameter like, the value of CPU Power; in the case of Co-Op RPL and RPL does not differ significantly from one another in any way. This is also able to be noticed in the test that was performed on the parameter of LPM Power. However, the findings of the simulation indicate that Co-RPL can reduce the average radio listen ratios by as much as 8% and can reduce the average radio transmission ratios by as much as 13%. This is due to the fact that we are decreasing the active participation of both nodes in communication to one, by putting one of the two nodes into sleep mode rather than listening on to a single packet by both of the nodes simultaneously. This, in turn, brings about a reduction in the number of packets that are sent out, which in turn brings about a drop in the radio transmission ratios.

The term "duty cycle" refers to the proportion of clock cycle that a load or circuit is "ON" in relation to the amount of clock cycle that it is "OFF." The Radio Duty-Cycle, abbreviated as RDC, is responsible for monitoring the time that nodes spend sleeping. This is the most crucial aspect since it is the one that is responsible for selecting exactly when the packets will be delivered, and in addition to this, it is the one that is accountable for ensuring that the node is awake at the time that the packets are scheduled to be received. According to the results of the simulations, the Co-Op RPL has the potential to cut the average duty cycle by 20% in comparison to the conventional RPL as shown in Fig. 5.

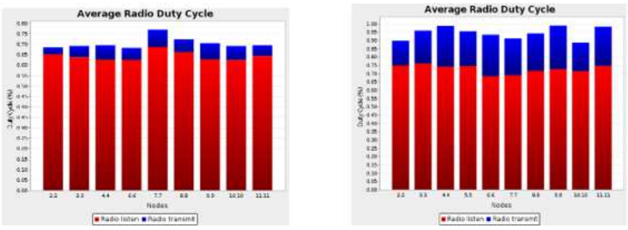

Fig. 5. Average Duty Cycle by nodes in CoOp-RPL & Conventional RPL

V. Conclusion

In this work, we presented our notion for an enhancement to RPL that we name Co-Op RPL. This improvement makes use of the Active/Sleep concept in conjunction with the Round Robin Algorithm in order to selectively choose the node from a set of cooperative vectors to be active. This active node is used to communicate packets within the network while the other nodes are sent to sleep. This results in a reduction in the number of nodes that participate in communication and helps to conserve the energy that is still available to the nodes.

According to the results of the simulation, it appears that, in contrast to RPL, Co-RPL has lower the average radio listen ratios by up to 8% and lower the average radio transmission ratios by up to 13%. The fact that it uses less energy overall is directly attributable to all of these positive changes and improvements.

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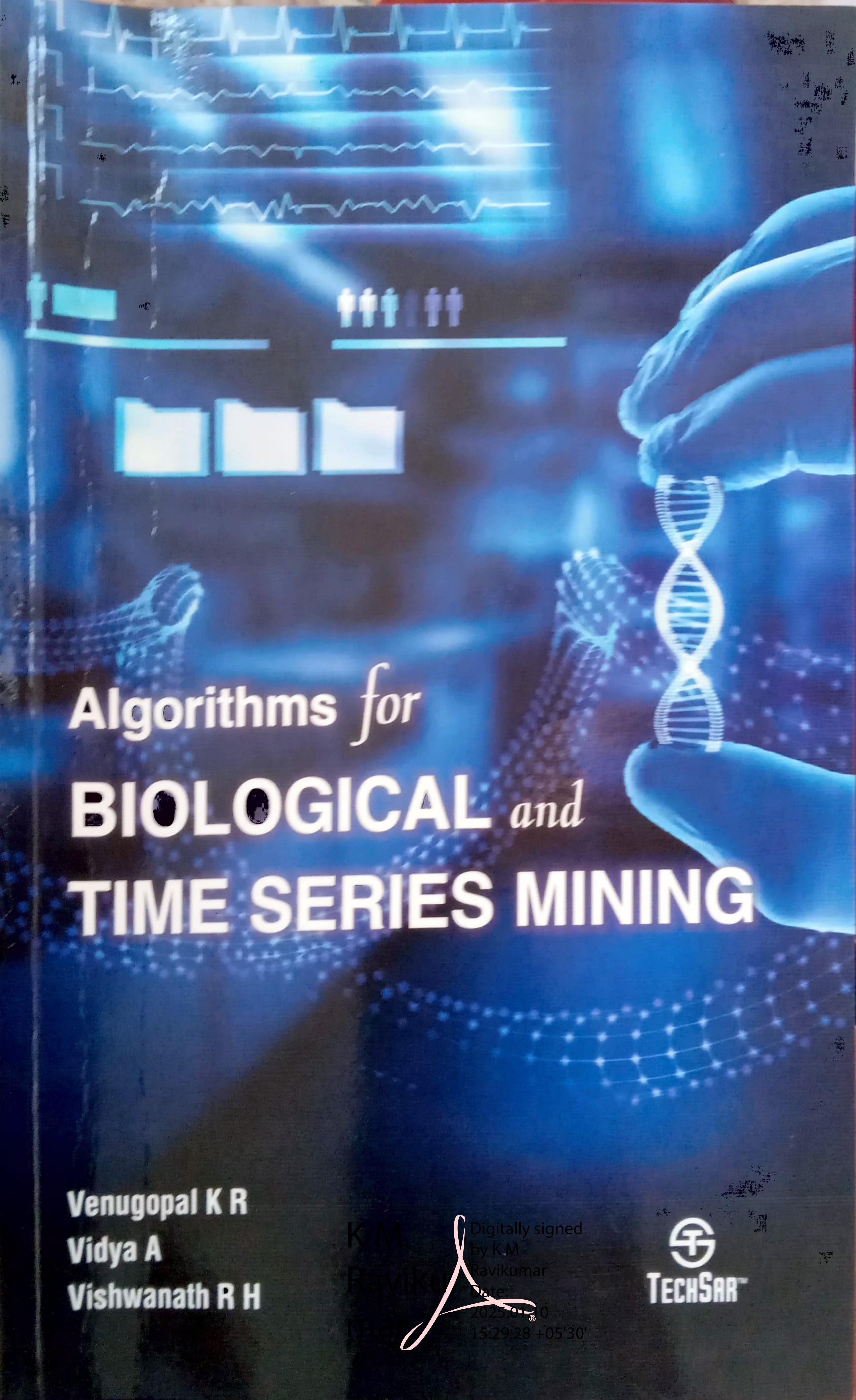

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4435-36/7, Ansari Road, Daryaganj
New Delhi-110002 (India)
Email: tech info@techsarworld.com
Website: www.techsarworld.com

ISBN: 978-81-968876-1-2

Published/Printed by Krishan Makhijani for I.K. International Pvt. Ltd., 4435-36/7, Ansari Road, Daryaganj, New Delhi-110002

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The book gives an insight into the research in the fields of Wireless Sensor Networks by providing security while routing the data. It focuses on the networking aspects of Wireless Sensor Networks and covers security issues related to data aggregation, multiple domain routing, geographical routing, multipath routing, adaptive routing, node authentication and clustering. This book is useful to a wide audience including academic researchers, research engineers and professional engineers. It is also suitable as a supplementary reading for Computer Science course at graduate/postgraduate level.

Venugopal K R is the Vice Chancellor of Bangalore University. He served UVCE and Bangalore University for over the last four decades. He has eleven degrees including two PhDs, one in Economics from Bangalore University and another in CSE from IITM. He has authored and edited 86 books and published more than 1200 papers in international conferences and international journals. He has awarded PhDs to 30 students informally guided more than 150 research scholars and supervised more than 700 Post Graduate dissertations in Computer Science and Engineering. He has 40 patents to his credit. He received IEEE Fellow and ACM Distinguished Educator award from USA for his outstanding contributions to Computer Science and Engineering and is the first professor to receive this highest academic award at the university level in this country. He was a Post Doctoral research scholar and visiting Professor at University of Southern California, USA.

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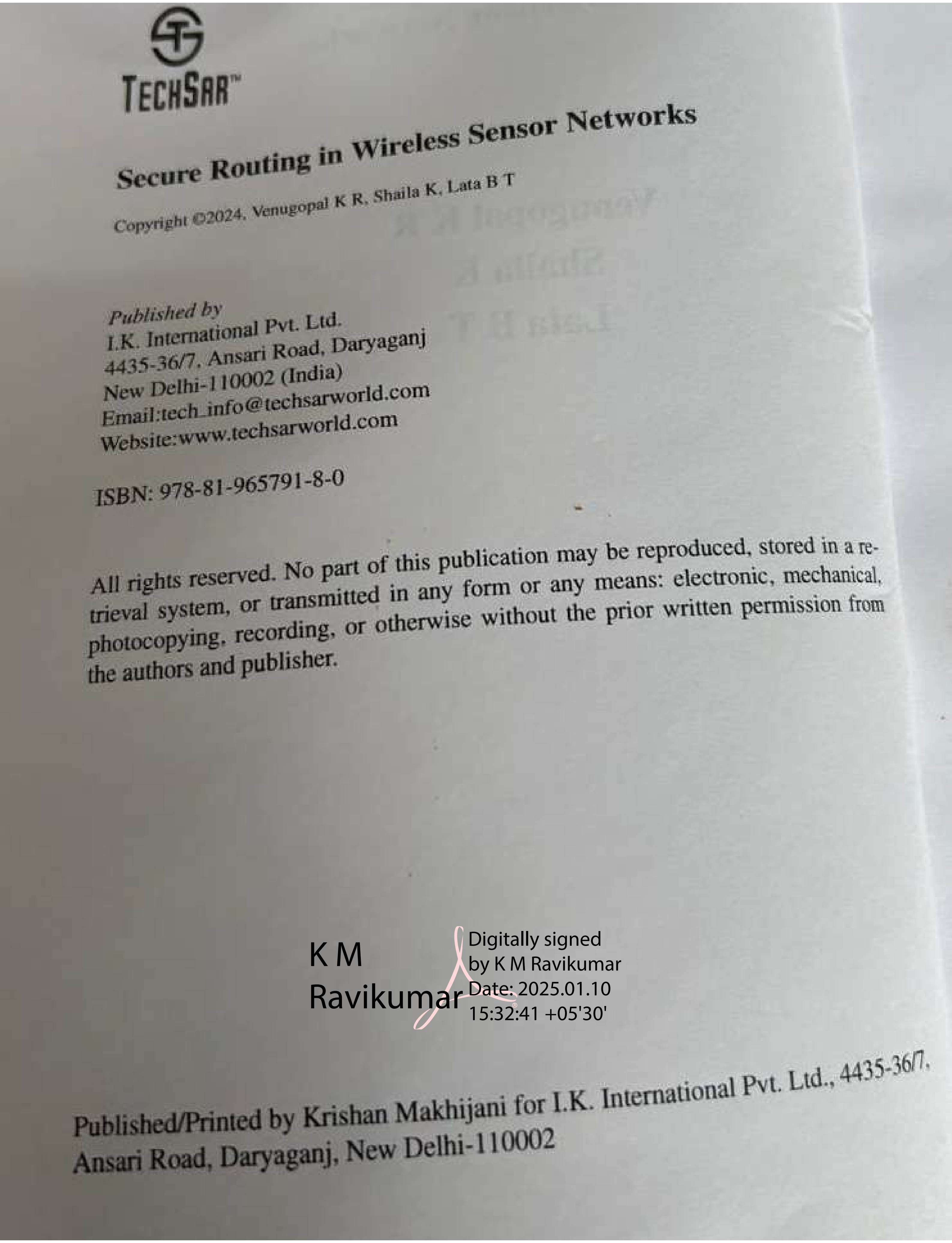

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Website:www.techsarworld.com

ISBN: 978-81-965791-8-0

Published/Printed by Krishan Makhijani for I.K. International Pvt. Ltd., 4435-36/7, Ansari Road, Daryaganj, New Delhi-110002

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