Performance Analysis for Network Coding Using Ant Colony Routing

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Abstract

The aim of this thesis is to conduct performance investigation of a combined system of Network Coding (NC) technique with Ant-Colony (ACO) routing protocol. This research analyses the impact of several workload characteristics, on system performance.

Network coding is a significant key development of information transmission and processing. Network coding enhances the performance of multicast by employing encoding operations at intermediate nodes. Two steps should realize while using network coding in multicast communication: determining appropriate transmission paths from source to multi-receivers and using the suitable coding scheme.

Intermediate nodes would combine several packets and relay them as a single packet. Although network coding can make a network achieve the maximum multicast rate, it always brings additional overheads. It is necessary to minimize unneeded overhead by using an optimization technique.

On other hand, Ant Colony Optimization can be transformed into useful technique that seeks imitate the ant’s behaviour in finding the shortest path to its destination using quantities of pheromone that is left by former ants as guidance, so by using the same concept of the communication network environment, shorter paths can be formulated.

The simulation results show that the resultant system considerably improves the performance of the network, by combining Ant Colony Optimization with network coding. 25% improvement in the bandwidth consumption can be achieved in comparison with conventional routing protocols. Additionally simulation results indicate that the proposed algorithm can decrease the computation time of system by a factor of 20%.

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Acknowledgment

I would like to thank number of people who have spent their time helping me with this thesis and made it in one way or another possible. First, I would like to thank my supervisor, Prof Hamed Al-Raweshidy for his support and guidance in this thesis and for chairing the examination committee with his motivating suggestions numerous reviews in many stages of my work till the final outcome.

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1 Introduction

1.1 Introduction

The world of telecommunications and Internet has experienced some drastic changes during the past years due to new advanced technical inventions and higher users' demand. A Network that consists of many nodes requires lot of resources in order to send multicast information to multiple destinations. Therefore, it is efficient to compress those information into organized small size packets at them sources before route the information intermediate nodes in the network. Those packets, however, are needed to be replicated at intermediate nodes in case of many destinations that are expecting for those packets what is called intermediate nodes in case of many destinations that are expecting for those packets results in loss in the network resources.

Recently, Network Coding (NC) [1] becomes an important field in information society due to its benefits that can offers. Several publication studied specific multicast topologies showing that, network coding results in better throughput than pure directing onward [2][3]. The key idea behind Network Coding is to manipulate and combine information from different sources at intermediate nodes before transmitting them again to the next nodes [4]. In other words, network coding combines the principle of coding theory and routing protocol by allowing links from different combinations of encoded information nodes in network can achieve the routing and encoding functions so it can increase the capacity of multicast network, increase services quality and decrease service time [5].

Ant colony optimization (ACO), on the other hand, is a well-known optimization algorithm that can solve very complicated optimization problem [7]. The Ant Colony algorithm aims to look for an optimal path in a graph, based on the behaviour of ants seeking a path between their colony and a source of food. Thus, ants spread pheromone while they are walking and searching the food. This pheromone helps to find back road towards their nest. An ant can decide from which path should go next when it reaches a crossroad by sensing the pheromone. However, are associated randomly with paths and might varied dynamically when ants searching food.

The concept of Ant colony optimization has been employed in lot of works to solve several telecommunication optimization problems [8]. Those problems including vehicle routing problem [9], graph colouring problem [10], and the well-known travelling sales man problem [11]. The difference between ACO and other traditional routing protocols is that ACO depends on pheromone concentration as routing metric while other routing protocols use delay and bandwidth.

Routing in ACO is accomplished by sending ants rather than routing tables in traditional routing protocols [15]. In addition, in contrast to traditional routing protocols where the routing control information and data information are exchanged and sent separately using different channels, with ACO routing control and data information can be carried in data packets [16].

1.2 Motivation of the Research

Network systems became more and more complex in their design and it expected to have a significant growing in the number of intermediate nodes in near future. Network Coding was first proposed, as novel informatics technique, to be used in multicast networks in order to boost up the performance of the network. Great efforts have been made to solve two principal issues in network coding last few years: coding method and routing.

For the former issue, many of methods have been discussed and proposed in publication and, linear network coding (LNC) scheme was found to be the most promising network coding scheme [6]. Thus, by using linear network coding give us the flexibility to perform network coding in a completely decentralized manner. Studies, however, have been made on the latter problem especially in multicast environment.

The idea of having Ant Colony algorithm to find an optimal path in a graph, based on the performance of ants looking for a path between their colony and a source of food , also by having something simple as ants to find a solution for complex computation problems seemed interesting, These new techniques can be used to reduce time consumption to solve telecommunication optimization problems.

1.3 Contribution and Objectives of Research

The significant aim of this research is to improve the system performance in a multicast-based network system. The focus will be on improving multicast rate and reducing packets latency.

The objectives of this research are:

- To propose a network framework that combines the Network coding theory with Ant Colony as routing protocol.
- To analyse the system performance in term of throughput and packet delay and bandwidth consumption

Through the thesis, simulation-based analysis has been taken in a network system to highlights the benefits of Ant Colony Optimization routing protocol. Review the area of Ant Colony techniques and Network Coding multicast to understand their principles and operations, as applied to the subject of this research. A comprehensive system level simulator has been developed to study and present the gain in the performance of Network Coding and Ant Colony Optimization as routing protocol in different scenarios.

1.4 Thesis Outline

This thesis consists of five chapters organised as follows:-

- Chapter one gives a basic introduction to the research and the motivation and objective of this thesis.
- Chapter two briefly describes Network Coding and its features and it also covers some of the background of Network Coding research and properties studied as well as cover the benefits of Network Coding and why Network Coding is used and reviews some of Network Coding application in this chapter, also briefly reviews packet forwarding multicast technique.
- Chapter three introduces the Ant Colony Optimization and gives overview of the Ant Colony and presents the understanding of the ACO algorithm that is provided through the double bridge experiment and description the framework of Ant Colony

Optimization algorithm design and review Ant Colony Optimization combinational optimization problem in routing and cover some of ACO application.

- Chapter four describes performance evaluation and comparison between Network Coding and Ant Colony Optimization of the system model adopted in this work and implement the simulation using Matlab and presents results of system-level performance analysis.
- In chapter five the conclusion of this thesis is drawn along with some future research topics.

2 Network Coding

2.1 Overview

Communication networks has been extended to various contents such as, the Internet, peer-to-peer networks, the cellular networks, wireless networks, and last but not least the sensor networks. Such systems are becoming essential parts to daily life.

There have been substantial efforts in the research communities devoted to the designing, operating and managing of networks. Information data are independently produced at the sources, transmitted in unit of packets and routed throughout the network.

Combining independent packet streams, however, allows better manipulation the information to fit the network environment and adapting the demands of specific traffic patterns.

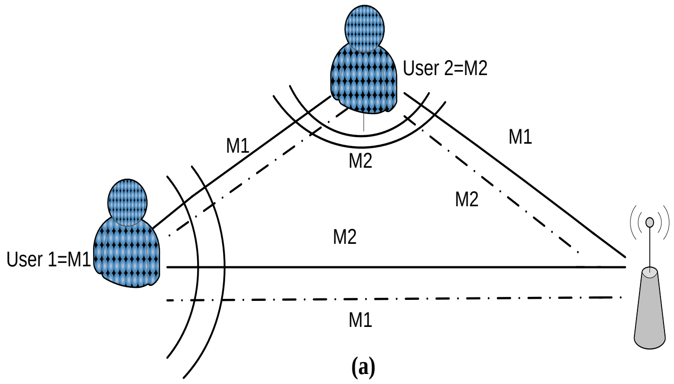
To this end, the concept of network coding has appeared to archive such purpose. This chapter gives an overview on Network Coding with multicasting routing protocol and reviews its major features. Also, it provides insight on the existing works on Network Coding explain where and why network coding needs to be used.

2.2 Network Coding

Network Coding is a promising technique that made a big influence in information theory last decade. It changes the conventional idea of routing and to improve the network performance by performing encoding/decoding operations at intermediate nodes [12]. Thus, the packets, which are independently generated by the source nodes, are not necessitated to be processed separately by intermediate nodes. That indeed is in contrast to the traditional routing approaches where each node forwards received messages.

If the encoded packet is somehow lost, there is still a probability that this packet could be recovered, without any retransmission from the source node, by collecting it from any neighbour or set of neighbours. It is expected that NC able to offer benefit in various aspects of future communication networks.

The concept of Network Coding [13] has been extended into many informatics research areas, such as graph theory, multi-user information and coding theory, wireless communications, networking. It has been shown [14] that by adopting network coding the performance can be improved in terms of achievable throughput and delay. In the conventional networks, data packets are routed from the source node to each destination node through a chain of intermediate nodes, i.e., router in Figure 2.1(a). Each router performs the store-and-forward mechanisms in which the incoming packets are first stored in queues before being transmitted to the next node thereafter in difference to the store-and-forward operation.



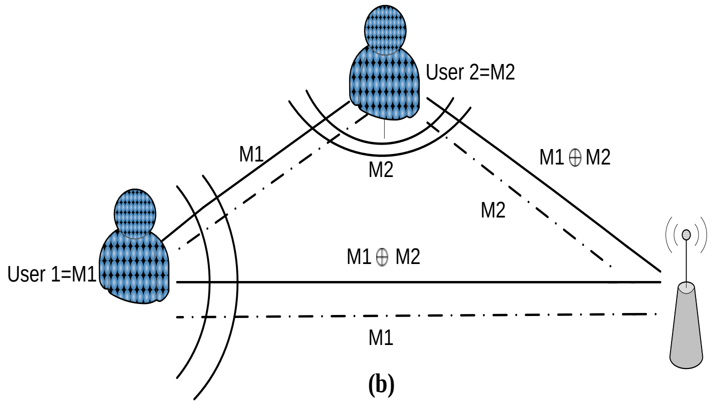


Figure 2.1: Network Coding Communication; a) store and forward communication network, b) Network Coding communication network

As shown in Figure 2.1(b) with network coding, the intermediate nodes alter the received data packets before transmitting new encoded packets. In other words, the intermediate nodes perform a processing technique and encode the packets for the intention of increasing the capacity or the throughput of networks, for example, the multicast communication channel.

Network coding allows intermediate nodes to combine the packets from different sources and forward the coded packets. When sending data to multiple destinations at the same time, using network coding can obtain a high-multicast rate. Not each intermediate node is all required to be coded. This is because network coding has ability to code packets from different sources, hence only nodes with multiple input links are required to be coded. In practice, a basic optimization used for network coding is that just encode the nodes with multiple input. Compared among coding every node, this technique can decrease redundancy code overhead. Intermediate nodes do not require to code in these situation:-

- Node with single input link and single output link.
- Node with two input of and output links.
- Node with additional alternative nodes than input link

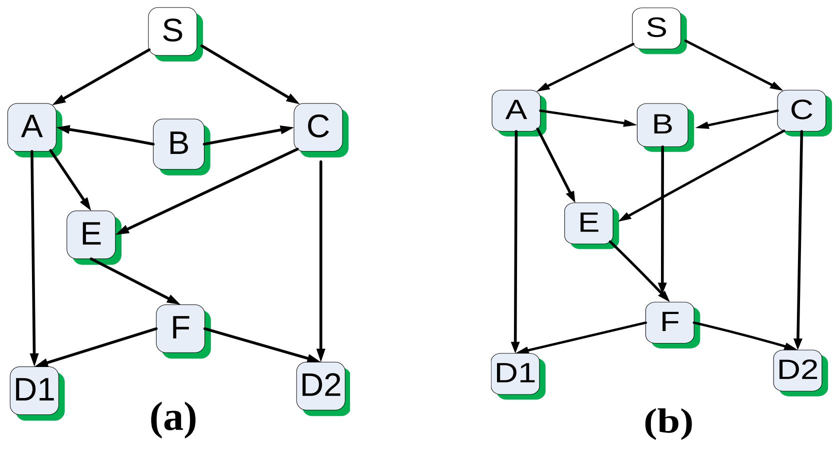


Figure 2.2: Optimization of Network Coding

In Figure 2.2(a), node A and node C has two input links and two output links, the two packets can independently forward in two output links, this does not require to insert network coding operation.

Node with additional alternative nodes than input links. In Figure 2.2(b), it is typically coded the packets in node E, but here with an additional node B, it can transmit packet p1 throughout this route: S-A-D1, S-A-E-F-D2, transmit packet p2 throughout this route: S-C-D2, S-C-B-F-D1. Into this route, it could be both perform the maximum multicast rate without using network coding. The additional node adds a new choice for nodes to transmit another packet. According to the three tasks, it could add a new method to network coding, use triple (Node, Input, Output) to every node, where Node is the existing node, Input is the number of input links of Node, as well, Output is the number of output links of that Node. This triple is very simple to get according to each node.

When nodes try to transmit packet, it looks up this triple, if the value of Output is more than the value of Input, then node transmit packet without network coding. Correspondingly, if Output is the same to Input, at that time code here is also not required. On the other hand, if the Input rate is more than Output rate, at that time it has been better add network coding here to obtain better network multicast.

2.3 Related Works

The field of network coding was first proposed in [15] in 2000. The authors considered a multicast-based networking in which a simple point-to-point communication network with a source being multicast information to a certain set of destinations. They demonstrated how network coding could improve the performance of a network and develop its robustness (Noise). Furthermore, they propose a simple classification of the acceptable coding rate area of a point-to-point communication as shown in Figure 2.3. This was the first step and important progress in understanding how throughput can be improved of a communication network.

Network coding was first brought in a multicast system to improve the throughput [16] by using network coding that allows information to be mixed. The authors of [17] have demonstrated that the throughput for the multicast systems can be improved by using a linear coding. The complexity of linear coding, however, is too high and exponentially increases with the size of the network.

In [18] the authors proposed an algebraic framework for network coding of the complexity if linear coding. Hence, by using their algebraic framework linear network coding analysis of distributed randomized network coding introduced in [19], the complexity of finding a linear solution can be reduced.

Meanwhile, the work of [20] considered single-source multicast-based system on acyclic delay-free graphs. They showed a similar bound on field size by different means by adopting distributed randomized network coding which was introduced in [21]. It has been proved in [22] that linear coding is insufficient in general and that the existence of a solution in some alphabet does not imply the existence of a solution in all larger non-finite field alphabets for undirected networks.

The authors of [23] demonstrated that network coding does not necessarily increase throughput for a single uncast or broadcast session. However, in the case of a single multicast session, the increase in throughput is bounded by a factor of two. In [24], the authors looked at two other applications of network coding to error correction.

In simple packet forwarding, if the packet is missing, there is no method to recover the missing packet unless the source transmits that packet another time or same packet is overheard from another neighbour.

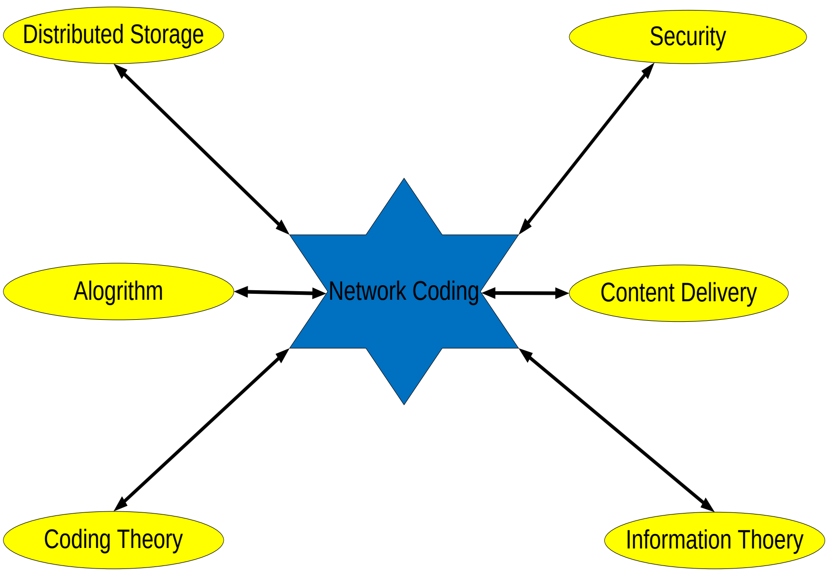


Figure 2.3: Network Coding Design

2.4 An Example for Network Coding

Figures 2.4(a) and (b) give a typical for the concept of network coding, namely Butterfly network coding. It indicates one source, S, two destinations, i.e., D_1 and D_2 in the network transmission range, and two intermediate nodes, i.e., E and F. The intermediate nodes that are located in the middle of source and destination can either receive and/or transmit one data packet at once for each unit of time.

The replication of the channels, between node S and nodes D_1 or D_2 represents the capacity of direct transmission from S to D_1 or D_2. Alternatively, the capacity of each channel is normalized to one. The amount of data is created at the source S and hence multicast to other nodes in the network, in multi-hop, while every node is passing on any of its received data packets to other nodes. This network is known as butterfly network.

Figure 2.4(b) demonstrates the concept of network coding where all links have normalized capacity. Node S sends two packets m_1 and m_2 to both destinations D_1 and D_2.This multicast can achieve higher capacity of transmission, in theory destinations D_1 and D_2 can receive both m_1 and m_2.However, in the traditional routing method (store and forward), shown in Figure 2.4(a), node E performs the store and forward operation.

If node E forwards packet m_2, through links BE, EF, FD_1, FD_2 will only carries packet m_2. Although the receiver D_2 can receive both m_1 and m_2, the node D_1 can only receive m_2. Thus the nodes D_1 and D_2 cannot receive the two packets synchronously. Hence, in the traditional method, it is not possible to achieve the higher capacity of transmission.

Figure 2.4(b) shows the concept of network coding method, where node E combines m_1 and m_2 using XOR operation (denoted by $\oplus$ sign) and transmits m_1 and m_2 in a single transmission.D_1 and D_2 can both receive m_1 XOR m_2 through the decoding method D_1 can receive m_2 ($m_1 \oplus m_2$). D_2 can also receive m_1 and m_2 (through m_1 ($m_1 \oplus m_2$). Thereby, a higher capacity and shorter time of transmission can be achieved.

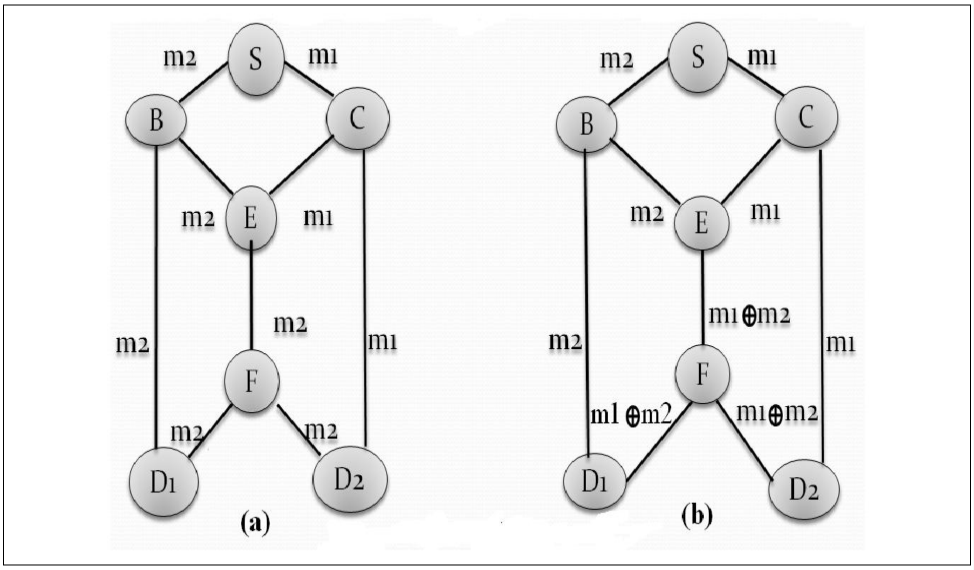


Figure 2.4: Butterfly Network.

2.5 Advantages of Network Coding

Network coding offers a number of advantages, along very diverse examples of communication networks. These advantages can includes, the following:

2.5.1. Throughput

The most significant benefit that Network Coding offers is the opportunity of improving throughput in certain network topologies [25]. The throughput benefit is obtained by using less packet transmissions, which results to send out more data in network [2]. To demonstrate deeply the following example shown in Figure 2.4 (a) Butterfly network consists of single source which multicasting information to multi-destinations.

The proper multicast connection can be established only if the intermediate nodes are allowed only to make copies of received packets for output then perform a coding operation. For instance, it can take two received packets, form a new packet by taking the binary sum, or XOR, of the two packets, and transmit the resulting packet to the next node. If the contents of the two received packets are the information $m1$ and $m2$, each constituted of bits, then the packet at the output is $m1 \oplus m2$, i.e., formed from the bitwise XOR of $m1$ and $m2$.

Once, the coded packet received by destination, a decoding operation is performed packets to recover the original packet. In fig, 1(b) destination D_1 regains m_2 by taking the XOR of m_1 and $m_1 \oplus m_2$, and similarly destination D_2 regains m_1 by taking the XOR of m_2 and $m_1 \oplus m_2$. According to routing, it could be communicated, for example, m_1 and m_2 to destination D_1, but it can only be able to communicate one of m_1 or m_2 to destination D_2.

2.5.2. *Mobility*

In mobile scenarios, the network topology is always changing over time. This leads to main issues for many routing protocols while there are frequent route updates and gathering new topological information [26][27]. Network Coding can solve this uncertainty by alleviating the needs for exchanging route updates.

2.5.3. *Reliability*

Other benefits of network coding (NC) are higher dependability and improved robustness (noise) [28]. By encoding, the packets into a single packet can certify that a single packet loss does not necessarily need re-transmissions [29]. While traditional routing procedure has not been acquired proper performance.

2.5.4. Enhanced Robustness

Additional benefit of network coding is enhanced robustness (noise) in packet transmission. Network coding obtains information packets and produces encoded packets, where includes information from all transmitted intermediate packets gave a sufficient number of encoded packets received, the transmitted packets can be recovered [30].

2.6 Application of Network Coding

2.6.1. Peer-to-Peer (P2P) File Distribution Network

In P2P content networks, the server divided file is into many packets before distributing to receptions, shown in Figure 2.5. The server or peer maintains connections to a limited number of neighbouring nodes that exchanges packets with them.

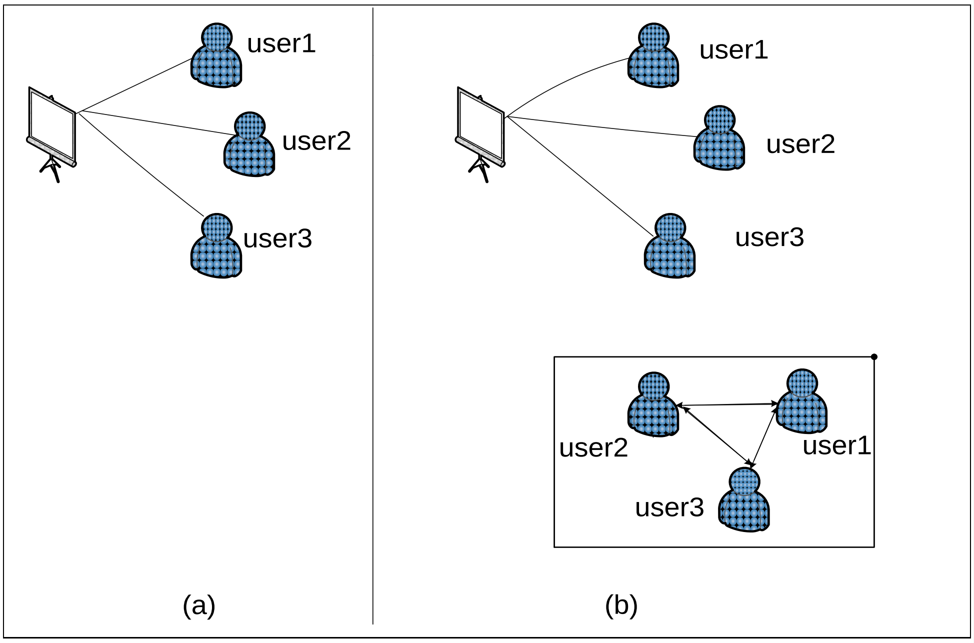


Figure 2.5: Peer to Peer (P2P) File Distribution Network.

The server needs first to download the original file, divide it and then distribute packets to their neighbouring peers. Using network coding in such distribution network is relatively useful. Thus [31], instead of supporting the server to spread the packets together, the peers determine randomly linear combinations of the packets before they forward them to next peers. The new coded packets can be created by linear combinations of the original packets. Therefore, Network Coding is much more robust and can improve the performance of P2P networks in several appearances.

2.6.2 Wireless Network

The wireless network medium is unreliable and unpredictable, has low throughput and insufficient mobility support. Network coding can be a useful candidate to be used in wireless environment to improve the performance terms of throughput, wireless bandwidth and delay. On the other hand, the characteristics of wireless networks present opportunities for the application of network coding [32, 33, and 34]. In the following example, Figure 2.6, the nodes S and D exchange the packets M_1 and M_2 via the intermediate node E.

In this example, it is assumed that the time is slotted, that is, one device either transmits or receives a packet during a given time slot. Figure 2.6(a) shows a standard approach, i.e., nodes S and D transmit their packets to the intermediate node E, and then E forwards each packet to the corresponding reception. With network coding in Figure 2.6(b), the node E first generates a new packet M_{ew} =M_1 XOR M_2 then forwards them to both S and D. Consequently, S and D can decode the packet from each other by using XOR function. Therefore node E that applies network coding to transmit once instead of twice, and the transmission requests twice instead of three times slots.

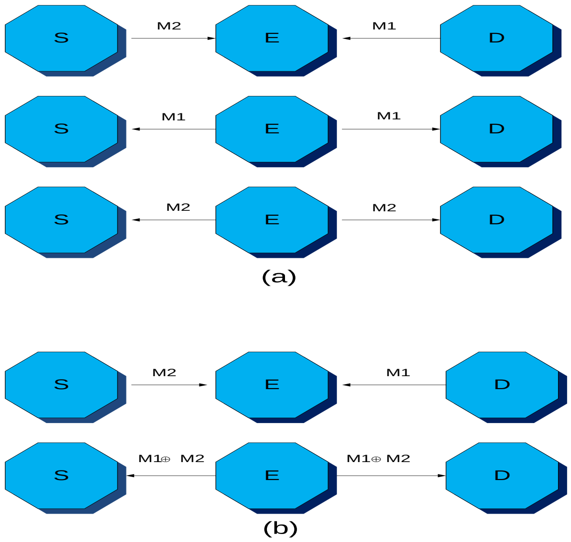


Figure 2.6: Wireless Network

2.6.3 Network Security

From security point of view, network coding can be able to offer both benefit in terms of secure Network Coding, the packets transmitted through a network observed by not permitted users, or still transformed by channel errors because packet are coded rather than routed. Network coding can be achieved and determine as the source combines the original data with random information and create a network that just the receivers can decode [35].

In the case of network coding, an attacker would not able to control the result of decoding method at the destination, without distinguishing all other coded packets, the destination will receive. As shown in Figure 2.7 the multicast information created at the source *S*, (*s*,*m*), depict the secure packet *s* and the randomness (*M)*.

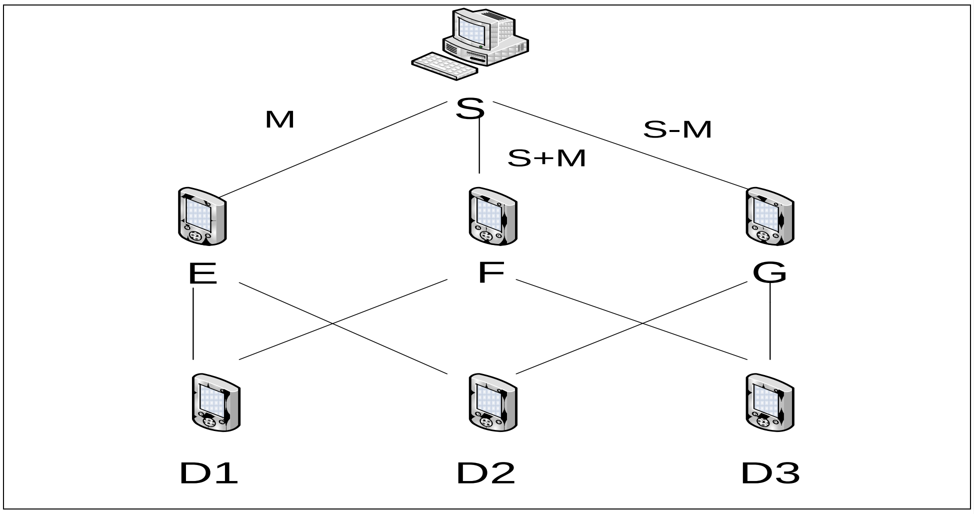


Figure 2.7: Network Security

Finally, it is easy to recover the secure data sent by *S* at any receiver node performing Network Coding.

2.6.4 Storage Network

The principle of storage networks is to store up information dependably in excess of periods of time using a set of servers. It has been shown in Figure 2.8(a) and (b) data A and C are stored up in two servers independently, but in Figure 2.8 (b) the network coding i needs no more than one server to store up these two data A and C therefore it has many benefits of network coding in minimizing the number of store-up servers [36].

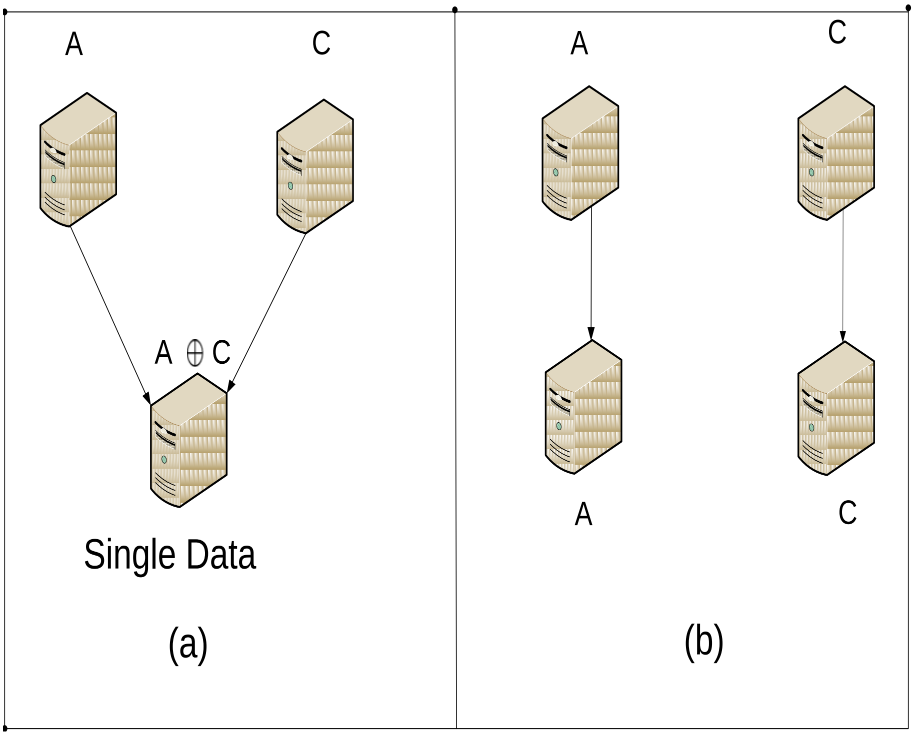


Figure: 2.8 Storage Network

2.7 Summery

This chapter has presented an overview of network coding architecture including the exploration of theoretical and operational networking issues from new perspectives that consider coding at network nodes. It has discussed the benefits of using NC in the modern communication networks by performing encoding/decoding operations at intermediate nodes. Combining independent packet streams allows better manipulation the data to make them fit the network environment and adapting the demands of specific traffic patterns. A linear network coding approach can asymptotically achieve optimal capacity in multi-source multicast networks. As the complexity of networks and network applications increases, so does the need for new techniques for operating and managing networks. It has shown how network coding can serve in developing fundamental network characterizations, as well as in enabling powerful new approaches to operational network issues by combining the packet that transmitted from source node at the intermediate node and send them in one transmission to the receivers that achieve high capacity of the network. Some practical applications for Network Coding have been summarized It has also presented in this Chapter.

3 Ant Colony Optimization

3.1 Concept of Ant Colony Optimization

Most networks turn into complications on a daily basis whether it is wired or wireless. Network Complications could lead to difficulties to manage the best indication of routes.The ant colony optimization technique (ACO) is a heuristic algorithm for solving a number of computational problems by finding solutions through graphs. The original algorithm was proposed to find for an optimal path in a graph based on idea of ant searching a path between their colony and a source of food, as it is shown in Figure 3.1, from here the ACO name came. The idea is then extended to solve a wider class of numerical problems [37].

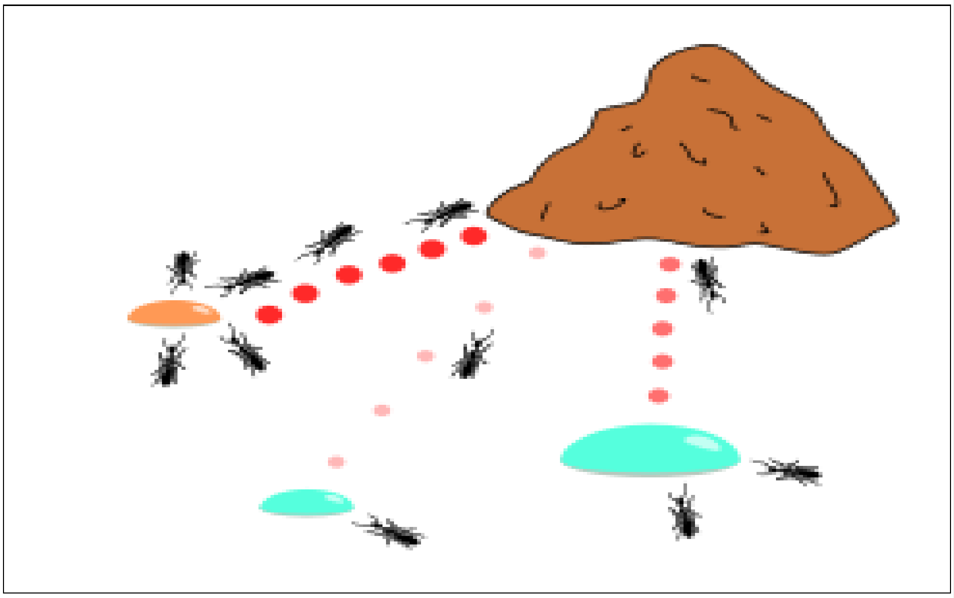


Figure 3.1: Concept of ACO [37]

3.2 The basis of Ant Stimulation

Ant, as a single unit, is very weak but as a part of a well-organized group or colony, it becomes very influential agent, working with other ants for the growth of the colony. Thus, the ants are communicating and cooperating to develop themselves and colonise the environment. This high self organizing principle allows a highly corresponding behaviour of the colony.

The researcher who studied the social behaviour of ants has been found that these ants are able to respond to significant stimuli signals and stimulate a genetically encoded reaction. Author noticed that the outcomes of these responses could play an important stimulus for both the ants that developed them and for the other ants in the colony. Author used the term stigmergy to depict this particular category of indirect communication in which the employees are motivated by the performance they have obtained [38].

Stigmergy can be defined as a scheme of indirect communication in a self-organizing developing communication scheme in which the individual components communicate with each another using their local surroundings. While ants are walking from or to a food source they deposit what it well known by pheromone on the ground. Other ants are able to follow each other by smelling this pheromone, which influences the selection of their path. Thus, the deposited pheromone forms a virtual path trail, which helps the ants to find sources of food that have been previously discovered by other ants [39]. Using random walks and pheromones between nest and one food source, the ants will leave the nest, follow the path, find the food, and return to the nest again in Figure 3.2.

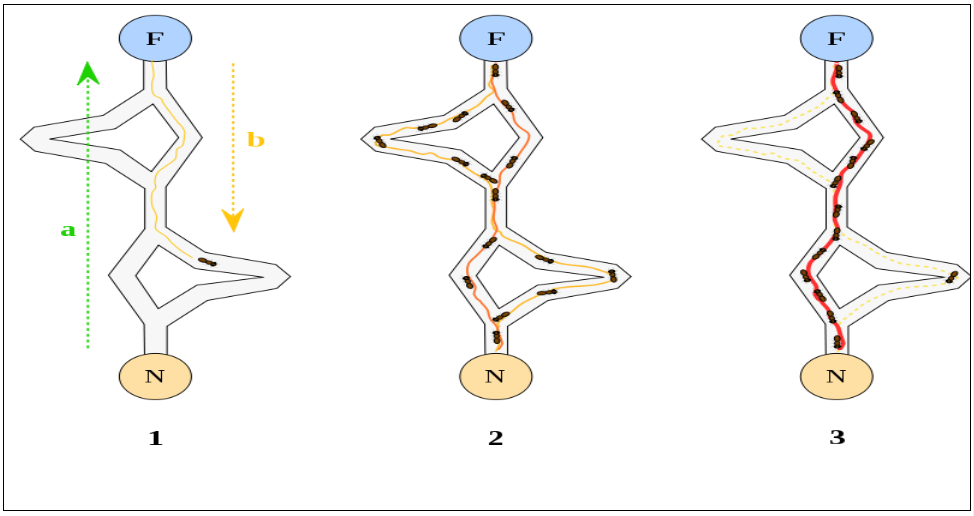


Figure 3.2: The Basis of ant stimulation [39]

3.3 The Double Bridge Experiment

Figure 3.3 shows an improved idea of the ACO can be achieved from the double bridge experiment where lower path P_2 is longer than upper path P_1. Starting from the point whilst there are no pheromones, ants obliged to perform a random selection between P_1 and P_2.

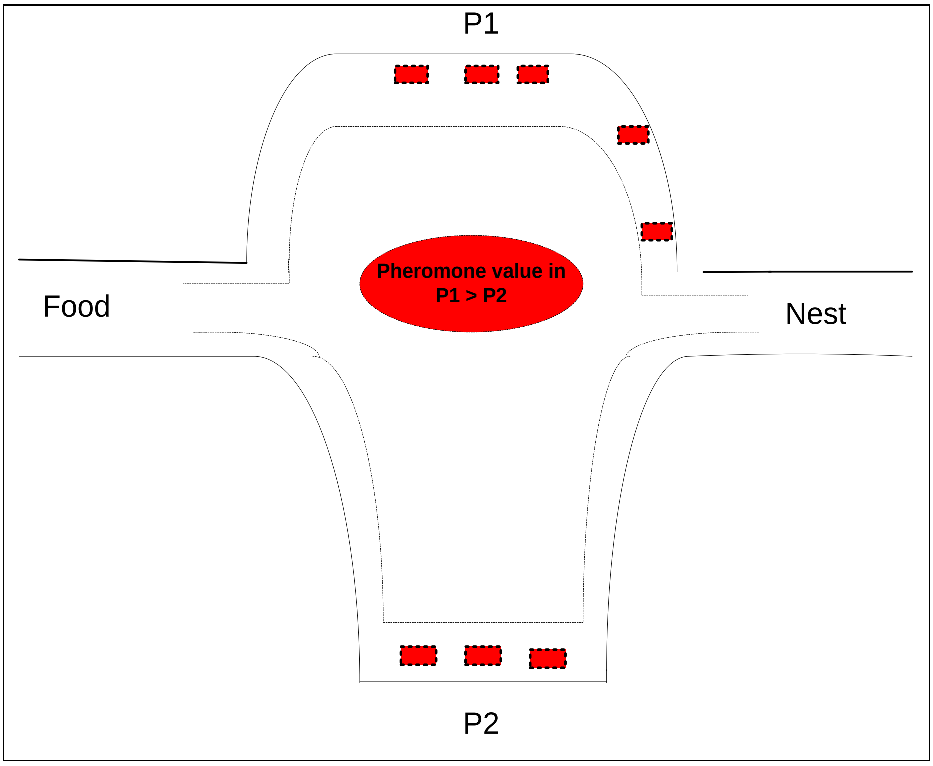


Figure 3.3: The Double Bridge Experiment

However, ants travelling along P_1 path will arrive at the destination faster and come back towards the source because the path it is shorter. Thus pheromone in path P1 start offset by more ants that are arriving the destination faster. As a result, the ants continue using path P_1, and hence the pheromone concentration increases further. The ant colony optimization technique is, therefore, an efficient way to find a shortest path between source and destination through this stigmeric way.

3.4 ACO Related works

Optimization problem are of high significance both for the industrial as well as for the research communities. Optimization problems can be included in several aspects such as train scheduling, resource allocation, shape optimization, telecommunication network design and routing problem, etc. The research community has applied many mathematics tricks in order to simplify many of these problems and solve those using specific algorithms. One of well-known problem is travelling sales man problem (TSP) [40, 41]. The TSP is problem of a travelling salesman who is needed to travel along a number of cities. The objective of the travelling salesman problem is to minimize total travelling distance between cities.

Ant Colony Optimization was proposed by Dorigo and colleagues in the early 1990s, as a novel heuristic method for the solution of difficult optimization problems [42, 43]. ACO belongs to the class of probabilistic techniques, which algorithms used to solve difficult combinatorial optimization problems in a sensible amount of time [44]. As it was mentioned, the development of these algorithms was motivated by the living-style of ant colonies of how ants can find shortest paths between food sources and their nest. Thus, when ants are searching for food, they firstly discover the surrounding area randomly [45]. They are spreading pheromone trail on the ground moving. Other Ants can smell pheromone and select their paths that easily noticeable by strong pheromone concentrations. Once an ant finds a food source, it measures the amount of the food and takes some of it back to the nest. During the return route, that ant spreads pheromone on the path; the quantity of spread pheromone indeed relies on the quantity and quality of the food. The pheromone trails will later be a lead to other ants to find the way to the food source [46].

3.5 The Structure of the ACO Met Heuristic

Figure 3.4 explains graphically the basic idea of an Ant Colony algorithm. For a given optimization problem to be solved, one first has to obtain a finite set of candidates, denoted by C, which can be used later to find the optimum solutions to the optimization problem. Thereafter, one has to introduce a set of pheromone values, denoted by T, which is commonly known as the pheromone model. The pheromone model is one of the solution components of the ACO heuristic. The pheromone model would be used to create, in probabilistic way, the solutions to optimization problem.

ACO algorithms update the amount of pheromone using formally generated solutions. The aim of update procedure is to focus the search in regions that contains good solutions. Particularly, the strengthening of possible solution depends on the previously solution. To learn which candidate contributes to good solutions can help to put them into better solutions.

In general, the ACO method attempts to solve an optimization problem iteratively by using the following two steps: first, the algorithm constructs the possible candidate solutions using a pheromone model, i.e., adopting parameterized probability distribution over the solution space. Second, those candidate solutions are used later to alter the amount of pheromone in a way that is viewed toward optimum solutions.

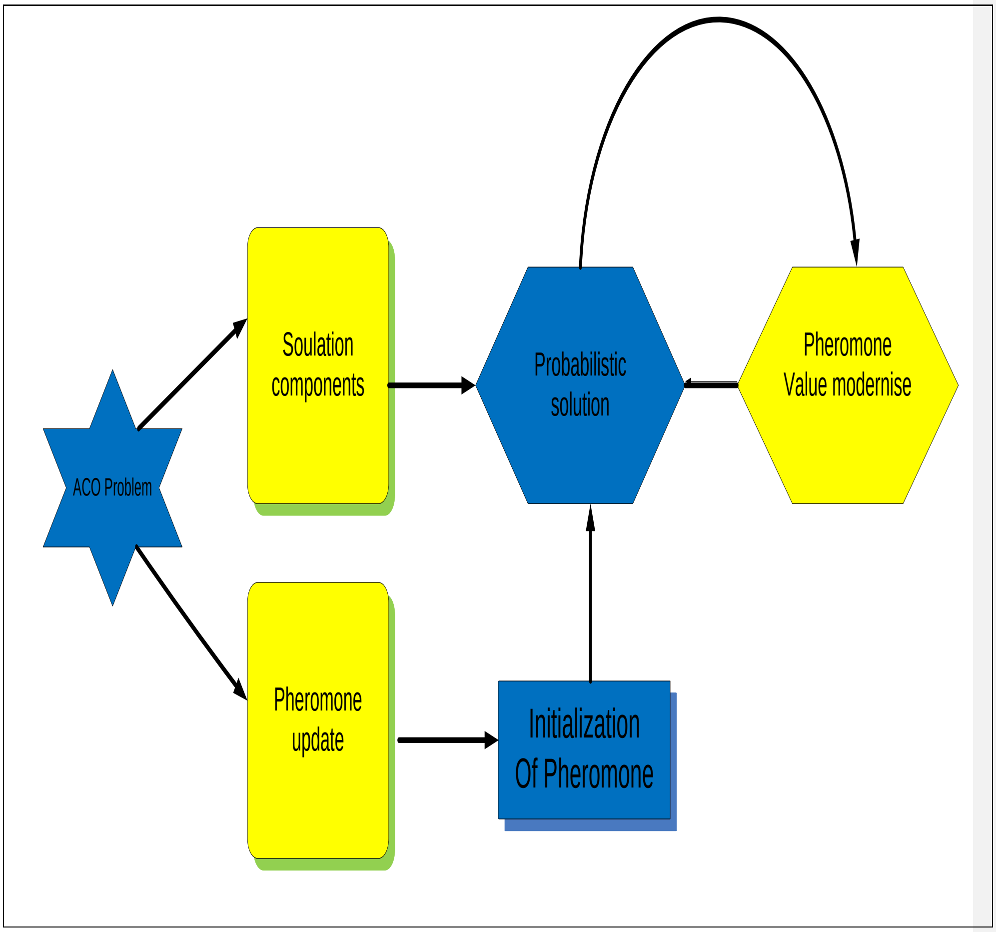


Figure 3.4: The Structure of the ACO Met Heuristic

3.6 Ant Colony Framework

The algorithm of ACO was designed based on the searching behaviour of real ants. Thus, the searching behaviour for ants is based on an optimis feedback from the cooperative manner. That is, following pheromone trail of the other ants and reinforce good solutions on a problem. A solution for a shortest path problem is created by the back and forth movements of ants on the same path where shorter distances due to the higher concentration of pheromone.

3.6.1 Designing ACO Algorithm

Let us consider an environment similar to the double bridge research. In Figure 3.5, a colony contains (n) ants that are moving two branches CD and CB from the nest, denoted by C. There is two food sources B and D and Router, R. *TCD* and *TCB* are defined following a random binary distribution of a constant probability (ρ) over [0, 1], where T is value of pheromone. It defined the following expression:

$$TCD_{i+1} = [Tcd_{i+1}, p \leq R_{CD}] \quad (3.1)$$

$$TCD_{i+1} = [Tcd_{i}, p > R_{CD}] \quad (3.2)$$

$$TCB_{i+1=} [Tcb_{i+1}, \rho \leq Rcb] \quad (3.3)$$

$$TCB_{i+1=} [Tcb_{i+1}, \rho > Rcb] \quad (3.4)$$

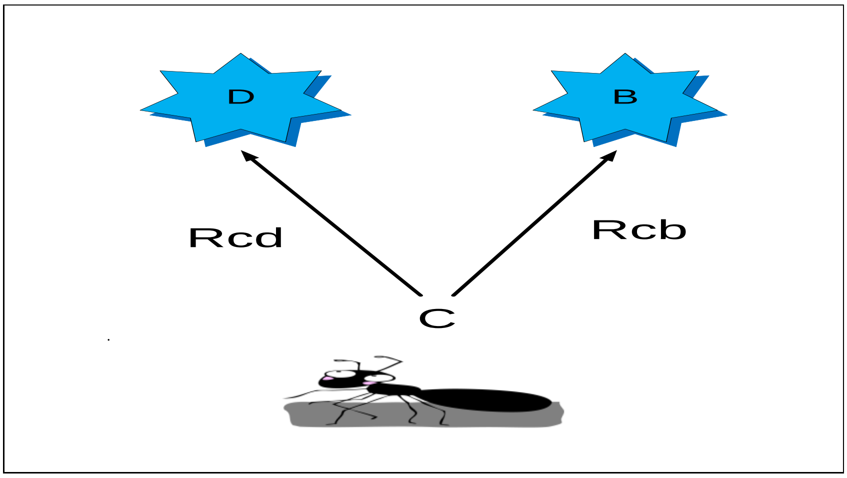


Figure 3.5: Designing ACO Algorithm

The Rcd (resp. Rcb) is the probability that an ant selects the node And B (resp. C) as the next state position in the environment. It is expressed by:

$$R_{cd} = \frac{Tcd}{Tcd + Tcb} \quad , \quad R_{cb} = \frac{Tcb}{Tcb + Tcd} \tag{3.5}$$

Where $R_{cd} + R_{cb}$=1.

It is clear from the equations that the more ants are moving a branch, the higher the probability on that branch will be, and the higher are the chances for that branch to be selected. Passing a branch by an ant is equivalent to the deposit of pheromone. This makes the pheromone plays a significant role in the selection of the moves of other ants in the area. Therefore, ACO algorithm is depended on the basis of the pheromone trail and the status transition moves.

3.6.2 Ant System Construction

ACO method was initially applied to the solution of the different optimization problem. Ant Colony is a heuristic algorithm of which the run time is kept within certain bounds by the principal while-loop in ACO Algorithm.

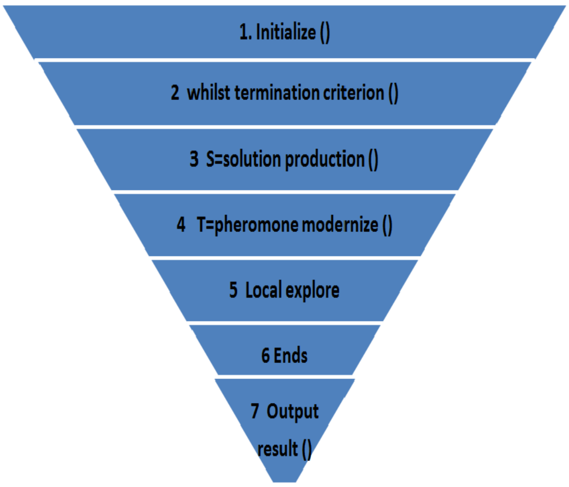


Figure 3.6: Ant System Construction

In each iteration, three algorithmic elements, which are Ant Based Solution production (), Pheromone modernize (), and local explore (), accumulate in the schedule activities concept as shown in Figure 3.6.

As shown in Figure 3.7 in first step, the ACO to initialize all the factors to reach the best iteration solution and the pheromone values. Hereafter, the main process on row (2) through row (6) in figure 3.6 will be recurring again and again till the stop condition is met.

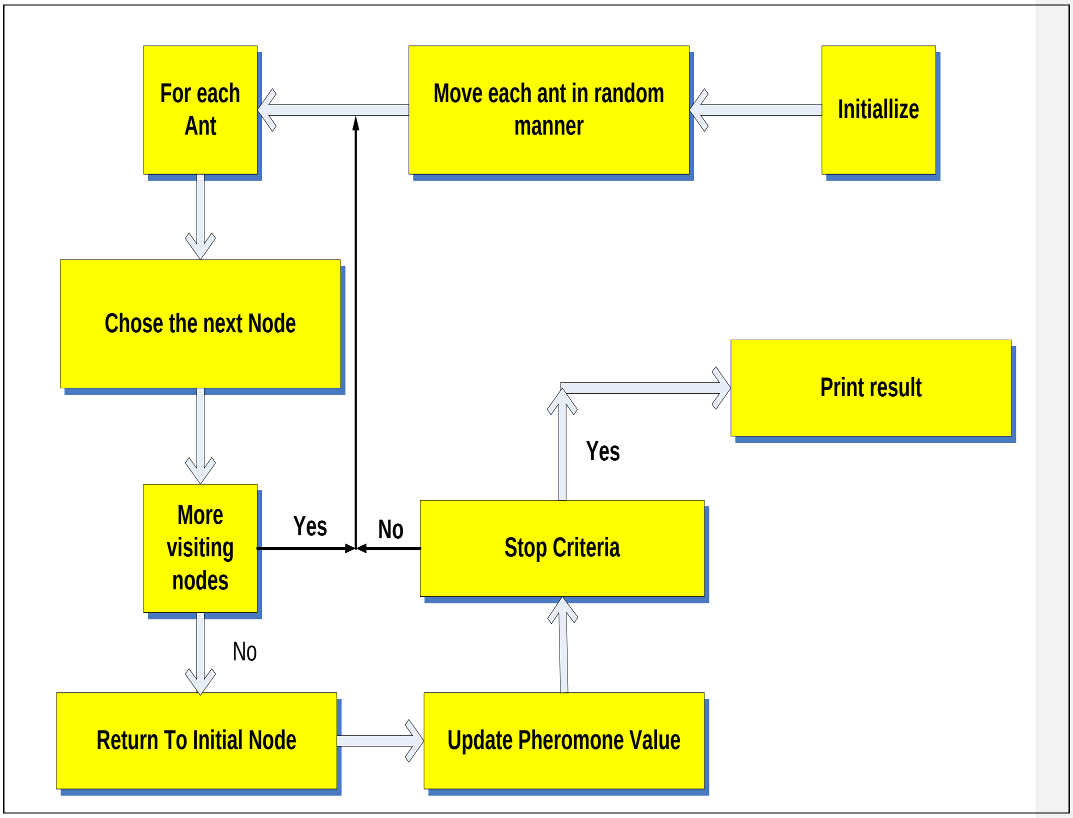


Figure 3.7: Flowchart of Ant System Algorithm

Another two additional procedures are also included in ACO, i.e., pheromone trail evaporation and domain actions. Pheromone vanishing (4) is the method by which the deposited pheromone by previous ants change downward over time. Practically, pheromone vanishing is required to prevent too fast convergence of the algorithm towards a non-optimum region. Local search process can be used to enforce centralized actions, which cannot be done by single ant such as the activation of a local optimization procedure, or the collection of global information.

3.7 Ant Algorithm Types

These are Example of pervious papers in ant colony optimization algorithm summarize in Following Table 3.1.

Table 3.1: Ant Algorithm Types

Algorithm	Reference
Ant Colonies	[47]
Improved Ant Net ACO Routing and Optimization	[48],[49]
Artificial Ants	[50]
Ant System Optimization	[51]
Ant colony optimization algorithm	[52],[53]

3.8 The Pheromones

Pheromone is a chemicals article of acting exterior the body of ants of the secreting individual to manipulate the manners of ants. Pheromone is similar in somehow to common memory. In the matter of the fact that, pheromone is external and not a part of the ants/ agents which confers to the ants an easy access for everyone. The memory is saved regards the arrangement of ground elements, the quantity of ants, etc. It is completely autonomous and still remains very simple.

In this performance it has been shown that two dissimilar sorts of pheromones are used.

- The first one is *away* pheromone is depicted in red and deposited by the ants which do not bring the food to the nest.
- The second one is the *Back* pheromone in opposition, the ants which find the food take them back to the nest deposited blue mark out behind them.

In itinerary of time, a global reduction of the pheromones through an influenced factor is applied, simulating the vanishing scheme. Therefore concentration of pheromones will be decreased in the non-optimal path, although high-quality solutions will contain filled pheromones in the optimal path the same as the ants remain using it. Ant's algorithm contains two mechanisms:

- Attractiveness
- Trail modernization

3.8.1 Attractiveness

In Ant System global modernizing is proposed to enhance the attractiveness of promising route but Ant Colony System mechanism is more useful because it avoids long convergence time via directly concentrate the search in a region of the best iteration solution of the algorithm. The attractiveness functions to utilize or else the initialization of the trail allocation. The attractiveness of search can be efficiently estimated through proceeds of lower bounds on the cost of the finalizing of an incomplete solution.

Whilst the lower bound value gets bigger than the current upper bound, it is clear that the considered search leads to a limited solution, which cannot be done, into a solution better than the existing best one. In many cases the values of the lower bounds decision is variables, can be used as sign of whether each variable will come into good solutions. TtHus provides useful method of initializing the trail values [54].

3.8.2 Modernization of the Pheromone Trail

The pheromone defines the adjustment of ant colony trail on the branches in the environment. As it is a volatile evaporating easily substance there is a time limit on its impact on the other ants. For such reasons, its computation is made with respect to three considerations:

- The pheromone quantity that deposited on path that has been used expressed by two parameters, the parameter of deposit relaying on the sort of ants used for the simulation, and a parameter of decompose for the deposit pheromone evaluated as a probability between [*0*,1].
- The parameter of deposit is usually located correspondingly to the inverted length of path; therefore, that short path has high pheromone deposited.
- The quantity of pheromone vanished after the ant has passed a path. The vanishing is set to rule the evaporation on a path, relay on the parameter of d decompose the pheromone deposit by the previous ant(s).On the other hand, for ant optimizations and simulations.

There have been defined two schemes for the pheromone modernizes:

1. The local modernization

The local modernise is the update of the pheromone on path when pass over by an ant toward the food as shown in Figure 3.8.

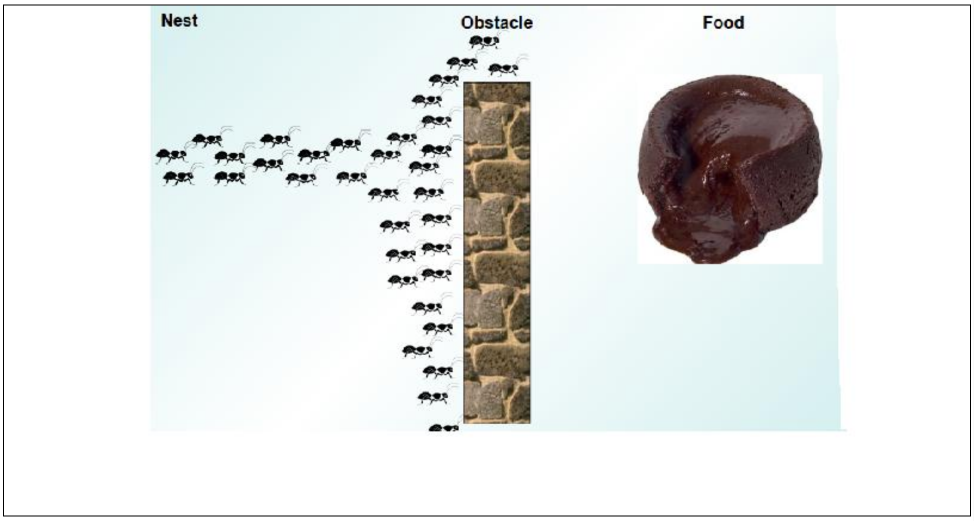


Figure 3.8: Pheromone before Modernise [56]

2. The global modernise

In Figure 3.9 the global modernise is the reinforcement of the best path created after iteration of the ants in order to find out the overall optimal path and updating of pheromone is heighted by dark blue line to the light blue line [55].

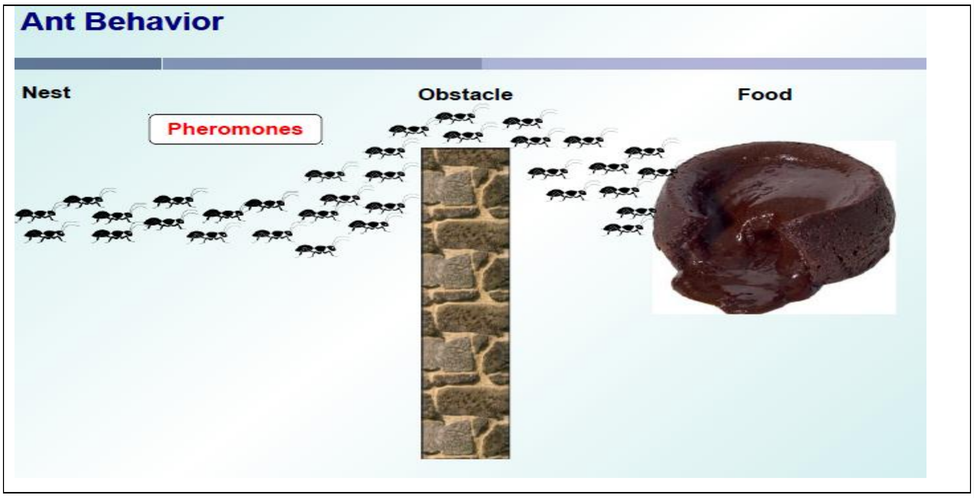


Figure 3.9: Pheromone after Modernise [56]

The key difference between ACO and the other met heuristics is in that ACO support the collaboration of ants. The “pheromone modernise of ACO compose it possible to spread the information of each solution to the others rapidly whilst each solution is being build thus that most the ants can simply spread the information they discover [56].

3.9 Combinatorial Optimization Problems

This section discusses the4 differences between ACO routing, traditional routing algorithms, such as the distance vector routing, and link situation routing in Figure 3.10 [57], of meticulous significance are the issues of:

- Routing Information
- Routing Overhead

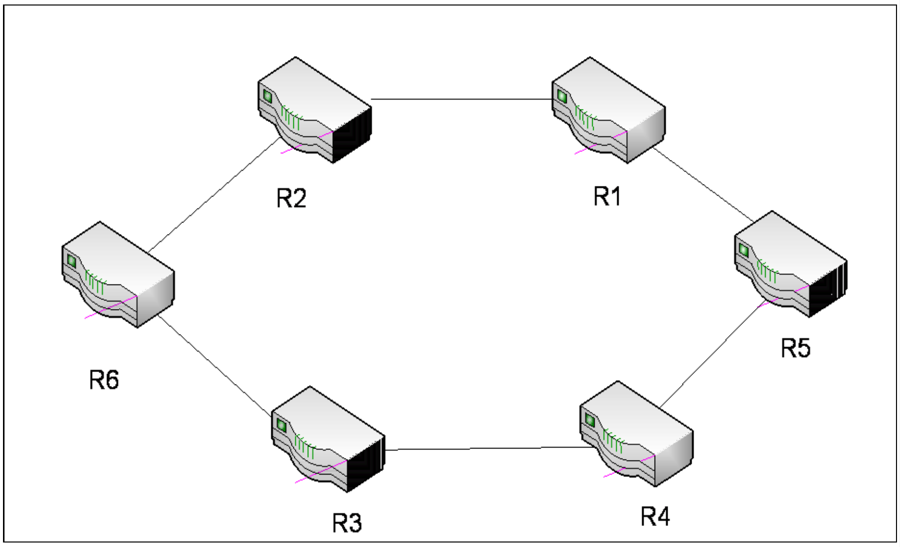


Figure 3.10: Combinatorial Optimization Problems

3.9.1 Routing Information

In traditional routing, a node R_i uses the routing information provided by all its neighbouring nodes and builds a complete routing table. For instance, let's consider the network shown in Figure 3.10. With traditional routing, the node R_6 depends upon the routing table that sends by it neighbouring, i.e., R_2 and R_3, and complete routing table. This table contains information regarding the distance between R_6 and R_1. In ACO, the links from a source to a destination are found independently and in parallel.

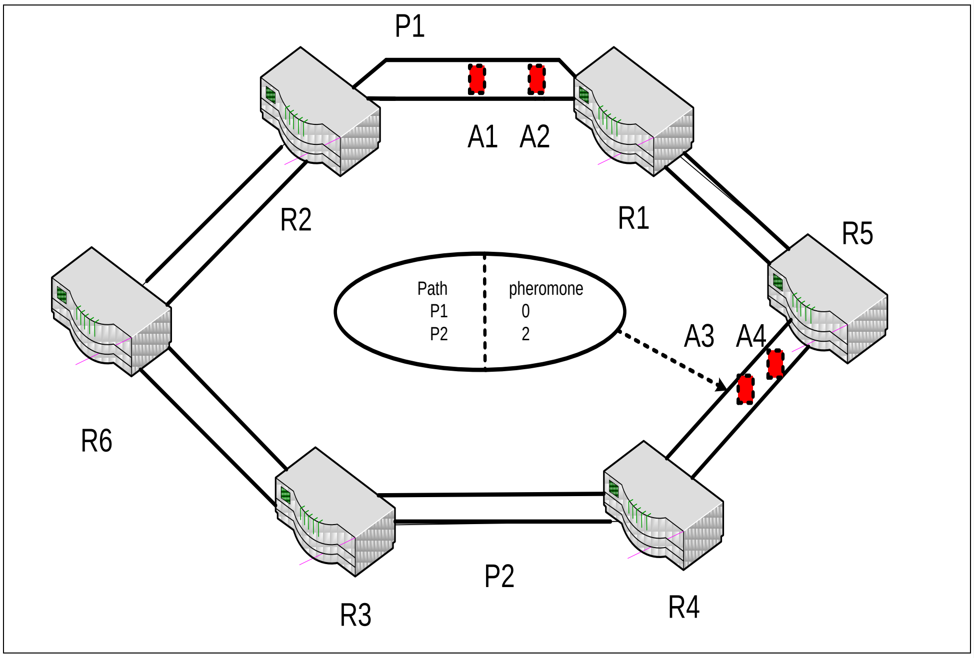


Figure 3.11: Problem Solving of Ants

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For instance, in Figure 3.11 four ants (A_1, A_2, A_3, and A4) travel independently from R_6 to R_5 via P1 and P_2.While the two ants A_3 and A_4 arrive at R5 first, it can be decide That P2 is the shortest route without needing to wait for A_1 and A_2 to reach R_5. When an ant reaches at a node, the equivalent pheromone value for a route is modernise to (2) , therefore, each of the pheromone table in a node can be modernise independently. In the network, which corresponds to the problem-solving situation, R_5 can instantly take the information in its pheromone table to route data packets to R_6 as any ant from either path reaches [58, 59].

3.9.2 Routing Overhead

In traditional routing, each node in the network needs to transmit the routing tables to every one of its neighbours. For a network with large number of nodes, the routing table becomes very large. Therefore, the routing overhead can be very high since traditional routing that is achieved by having each node send data packet to every other node in a network N through routing procedure. Moreover, multiple copies of the identical packets might be transmitted to the some node. On the other hand, routing update in ACO is achieved by sending ants rather than routing tables [60]. Even although it is noticed that the size of an ant might be different in dissimilar application, relaying on their functions implementations.

Generally, the ants are very simple agents and the size of ants is relatively small, in the order of 6 bytes [61, 62], because they are very simple agents. Table 3.2 reviews differences between ACO and traditional routing algorithms.

Table 3.2: Differences between ACO and Traditional Routing Algorithms

Comparison	ACO Algorithm	Traditional routing
Routing partiality	lay on concentration of pheromone	lay on transmission time
Routing operating cost	Low	High
Routing Table modernization	Modernise access in a pheromone table separately	Update access routing table

3.10 The Ant Net algorithm

The operation of ant net is based on two types of agents:

- Forward Ants who gather information about the state of the network, and
- Backward Ants who use the collected information to adapt the routing tables of Routers on their path.

An AntNet router contains a special routing table where each destination is associated to all interfaces and each interface has a certain probability. This probability indicates whether or not it is interesting to follow that link in the current circumstances. The router also contains a statistical model to store the mean and variance values of the trip times to all destinations in the routing table.On a regular time base, every router sends a Forward Ant with random destination over the network. The task of the Forward Ants is collecting information about the state of the network. In each router they pass, the elapsed time since the start is stored on an internal stack together with the identifier of the router . Then the next hop is determined. Normally this is based on the probabilities in the routing table.

There is however a small chance (exploration probability) that the next hop is randomly chosen. This is necessary to constantly explore the network and to be able to react fast to network changes like link failures or congestion. When the Forward Ant reaches its final destination again the elapsed time since the start and the identifier of the router are stored on the stack of the ant . The Forward Ant is transformed into a Backward Ant. This Backward Ant will follow exactly the same path as the Forward Ant but in the opposite direction. The Backward Ants use the information collected by the Forward Ants to update the different data structures in each router along their path. The time information on the stack is compared with the model in the router and based on these comparisons, the probabilities in the routing table are updated. When the Backward Ant arrives in the start router, it dies. Backward Ants have a higher priority than data packets, so that they are processed as fast as possible making the algorithm more adaptive. Forward Ants have the same priority as data packets, to suffer the same delays so that the algorithm can react to network congestion . A trip time better than the mean value will boost the probability on that interface, while a bad trip time will only slightly increase the probability. The variance value is an indication for the stability of the network.

3.11 Application of Ant Colony

This idea of Ant colony optimization algorithms have been employed to very complex optimization problems by creating artificial ants that trying to find the optimum solutions subject to the problem's constraints. Artificial ants can be seen as agents that imitate the behaviour of real ants.

It should be noticed, however, that an artificial ACO has some differences several characteristics that are followed original ACO such as artificial ants consist of a probabilistic preference for paths with a larger quantity of pheromone.

The ants apply an indirect communication scheme relaying on the quantity of pheromone deposited in each path.

3.11.1 Travelling Salesman Problems

One of the most well known problems that can be solved by ant colony optimization algorithms is the travelling sales man problem. In the matter of fact, the first ACO algorithm was proposed to solve the travelling sales man problem and find the shortest round-trip to link a series of cities. The original algorithm is relatively simple and based on a set of ants, each making one of the possible round-trips and move from one city to another according to some rules, i.e. [63,41]

- It is obliged to go around each city exactly once.
- The more the pheromone trail laid out on an edge between two cities, the greater the possibility that that edge will be chosen;
- Once the journey complete, the ant spread more pheromones on all edges it visited, if the journey is short;
- After iteration, a trail of pheromones vanishes.

3.11.2 Scheduling Problems

Scheduling is process of allocating of limited resources among tasks over time. Scheduling problems attracted more and more attention production and manufacturing industries, but also arise in a different objective.

- Job-shop scheduling problem (JSP) is an optimization problem in computer science in which ideal jobs are assigned to resources at particular times [64].
- Open-shop scheduling problem (OSP) is schedule to obtain minimum finish time for two-processor open shop together within processing time [65].
- Single machine total tardiness problem (SMTTP) in general it means the problem of scheduling job operations on a given number of available machine[66]
- Resource-constrained project scheduling problem (RCPSP) [67]
- Group-shop scheduling problem (GSP) [68]

3.11.3 Assignment Problems

The assignment process is to allocate a set of objects to a given number of resources subject to some restrictions. Assignments can be seen as a mapping problem with objective function that minimizes of the assignments done.

It can be employed in following problems.

- Quadratic assignment problem (QAP): In the QAPthere is m machines and n jobs. Each job consists of a set of operations, which must be processed on specified machines without preemption. The operations of each job are partitioned into groups on which a total precedence order is given. The problem is to order the operations on the machines and on the groups such that the maximal completion time of all operations is minimized. [69]
- Generalized assignment problem (GAP) there are a number of agents and a number of tasks. Any agent can be assigned to perform any task, incurring some cost and profit that may vary depending on the agent-task assignment. Moreover, each agent has a budget and the sum of the costs of tasks assigned to it cannot exceed this budget. It is required to find an assignment in which all agents do not exceed their budget and total profit of the assignment is maximized [70] [71]
- Frequency assignment problem (FAP) [72]
- Redundancy allocation problem (RAP) involves in the simultaneous selection of components and a system-level design configuration, which can collectively meet all design constraints in order to optimize some objective functions such as system cost and/or reliability [73]

3.11.4 Network Routing Problems

The network routing problem (NRP) is the problem of finding the lowest cost paths among all the candidates in the network. It is worth mentioning that if the costs are fixed, then the NRP is reduced to a set of minimum cost path problems. Each can be solved efficiently via a polynomial time algorithm [74, 75].

3.11.5 Vehicle Routing Problems

The Vehicle Routing Problem (VRP) apply the determination of an best set of routes for a set of vehicles to serve up a group of clients

- Capacitated vehicle routing problem (CVRP) [76]
- Period vehicle routing problem (PVRP) to find a set of tours for each vehicle over the period the aim of minimize total travel time and visit requirements [77]
- Split delivery vehicle routing problem (SDVRP) [78]
- Vehicle routing problem with pick-up and delivery (VRPPD) in considering the minimum of number of vehicle and transporting time [79]
- Vehicle routing problem with time windows (VRPTW) can be described as the problem of designing least cost routes from one depot to a set of geographically scattered points. The routes must be designed in such a way that each point is visited only once by exactly one vehicle within a given time interval, all routes start and end at the depot, and the total demands of all points on one particular route must not exceed the capacity of the vehicle. [80]

3.11.6 Set Problems

In separation problems, a solution to the problem under consideration is depicted as a separation of the set of available items subject tot problem specific constraints. The problem between a set of customer nodes with acknowledged demands of a node to minimize cost tree network, subject to capacity restriction for all links, it can be employed in the following problems:

- Set covering problem(SCP) [81]
- Set partition problem (SPP) [82]
- Maximum independent set problem (MIS) [83]
- Classification [84]
- Connection-oriented network routing In CON each packet is treated separately, making its way through the network independently. Each individual packet may take different routes through the network depending on the type of routing protocol used and the

amount of traffic on the network. As the packets travel along varying routes, they may not necessarily arrive at the designated location in sequence [85] [86]

- Data mining is the process of discovering new patterns from large data sets involving methods at the intersection of artificial intelligence, machine learning, statistics and database systems. The goal of data mining is to extract knowledge from a data set in a human-understandable structure and involves database and data management, data preprocessing, model and inference considerations, interestingness metrics, complexity considerations, post-processing of found structure. [87]
- Intelligent testing system [88]
- System identification in the field uses statistical methods to build mathematical models of dynamical systems from measured data. System identification also includes the optimal design of experiments for efficiently generating informative data for fitting such models as well as model reduction. [89]
- Power Electronic Circuit Design the process can cover system ranging from complex electronic systems all the way down to the individual transistors within an integrated circuit [90].

3.12 Summery

This chapter has presented the architecture of Ant colony optimization. The ACO is a heuristic algorithm for solving a number of very complex optimization problems. The idea behind it was inherited from ant's behaviour seeking food. This Chapter also gives a survey for some ACO-based techniques used for solving a number of very computational practical. These problems include several aspects such as train scheduling, resource allocation, shape optimization, telecommunication, and routing problem. Some practical application adopt ACO nowadays was presented. The structure of ACO as routing protocol and the key difference between ACO and the traditional routing protocols was discussed.

4 Performance Evaluation of Network Coding ACO

4.1 System Model

Let's consider a conventional butterfly-based system with multiple intermediate nodes as depicted in Figure 4.1. This system model has been implemented in Matlab. For convenience intermediate nodes, which relay packets from single source single destinations, indexed by $n \in N$. The source denoted as S, transmits a set of packet that indexed by $m \in M = \{1,M\}$.It is assumed that all packets are delivered directly at the destination. The special node S is called the source, while every other node may serves a sink. Each link between any two nodes, $l \in L = \{1, L\}$, has normalized capacity in which one bit of information can be sent per unit time. The source S generates and transmits a finite amount packet which designated to a number of destinations, i.e., multicast packets. The intermediate nodes on the network acts as multichip relay which forward the received packets to the other nodes.

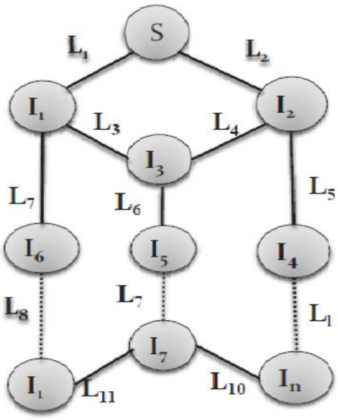

Figure 4.1: System Model

4.2 Linear Network Coding

For simplicity and without loss of generality, linear network coding (LNC) is considered in this work. Linear Network Coding is a paradigm shift in data transport. It helps to reduce the complexity for some hard optimization problems. Hence, when performing network coding the intermediate nodes are able to process and combine a number of packets received into one or more new outgoing packets as shown in Figure 4.2. It has been shown in [6] that, with Linear Network Coding, large network capacity can be achieved in multicasting environment, with relatively low complexity.

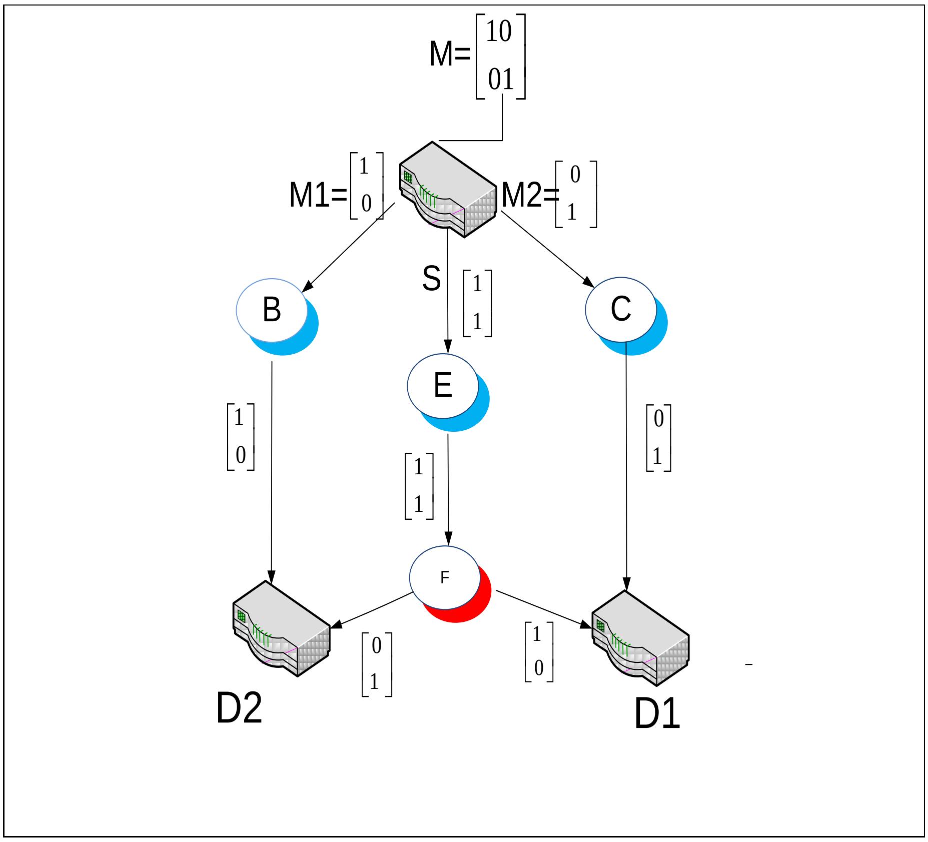

Figure 4.2: Linear Network Coding

4.3 Butterfly Network Simulations

4.3.1 Delay of Butterfly Network

Let's first examine performance gain of the system, in term of packet delay resulting, from network coding relative to traditional routing protocol. Here in, it is assumed a multicast transmission from a single node *S* to multi receiver. It is assumed that the source has a full buffer where there are always packets waiting to be transmitted. The comparison in delay performance is carried out through times that of the whole packet delivered at the destinations.

Figure 4.3 shows the reduction in delay that can be achieved through network coding. As it is shown, the gain in the delay is noticeable especially at large packet size due to linear combination between packets at the intermediate nodes.

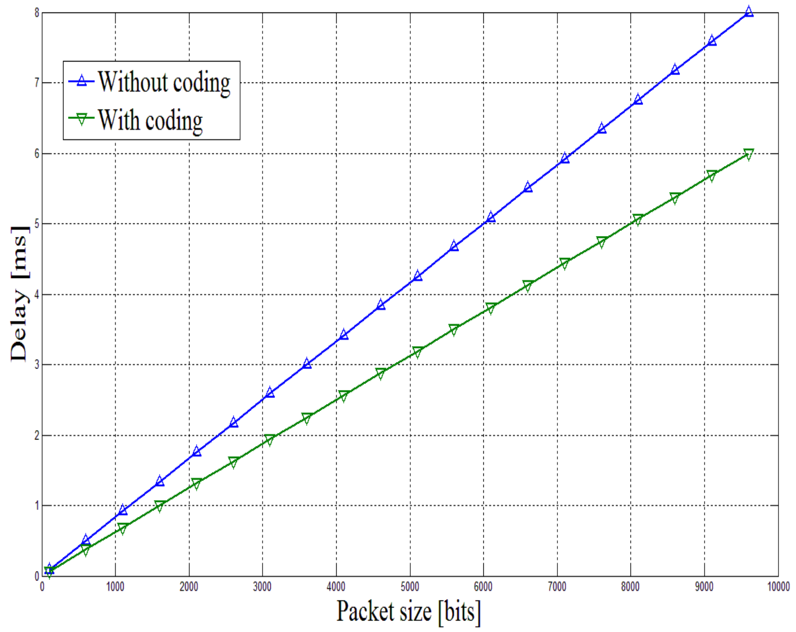

Figure 4.3: Delay vs. packet size

4.3.2 Throughput of Butterfly Network

Another gain in performance, resulting from network coding, is that it can increase the throughput of multicast traffic. Figure 4.4 depicts the system throughput for a butterfly system with and without using network coding. Without network coding, the destinations receive packets from the single source at half rates. With network coding, however, the packets from source nodes are mixed at the intermediate nodes in such received packets from both source are delivered with a destination with the same rate and another destination does the same rate. Therefore, with network coding, data can send at 100% rate of the link capacity to each receiver, while without, it can only send at 50% rate to each receiver.

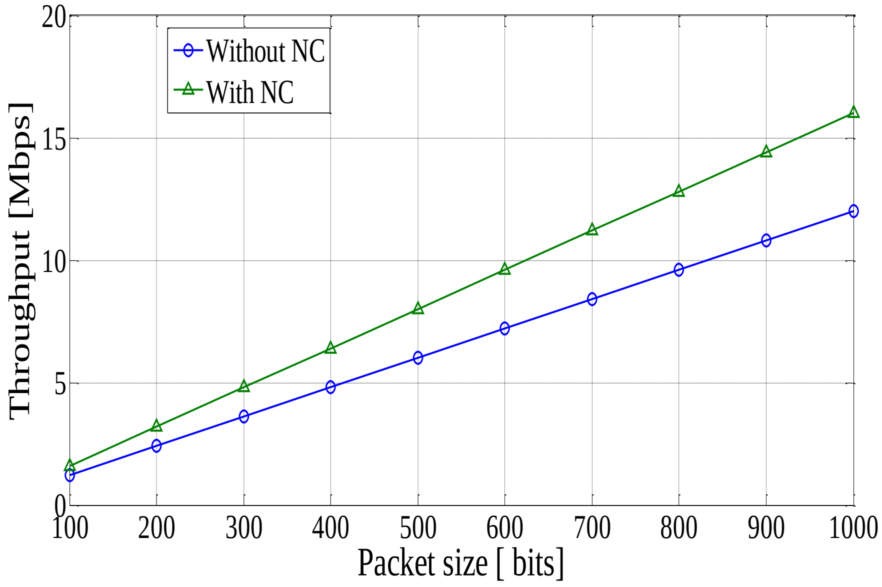

Figure 4.4: Throughput vs. packet size

4.4 Ant Colony Optimisation

As mentioned earlier, the shortest path is expected to be estimated using ant colony algorithm. The coding capable nodes can be detected by examining a set of links. Let the cost path between two nodes (*i*, *j*) denoted as the amount of pheromone spread it on that link *l*. The pheromone information is changed randomly during problem solving progress to reflect the experience gained by ants. Hence, ants randomly choose paths based on the amount of pheromone. The size of deposited pheromone on a path is proportionally equal to the quality of that path. The quality here means the length of that path, more amount of pheromone are deposited on the shortest paths, *L*, which became the candidate paths for Ant Colony optimization solution.

Lets define, $T_i\ j^k(t)$ as size of pheromone in the link (*L*) connects between node *i* and node *j*. At each iteration of the Ant Colony algorithm, an ant goes from a joint node, i.e., intermediate node, *i* to node *j*. This reflects intermediate node accomplished intermediate solution. Furthermore, in each iteration, an ant (*m*) calculates a set *L* of feasible paths, and moves to one of these with a probability of moving P_{ij}^k .The probability of moving P_{ij}^k depends on two factors: the attractiveness (heuristic value) n_{ij} and trail level T_{ij}.The former factor can be calculated using some heuristic methods that are pointing the a priori desirability of that move, while the latter factor reflects the history of making this move in the past. In other words, it acts as a posterior indicator of the desirability of that move. Trails are regularly updated when all ants have a completed list of their solution.

It also indexed as increasing or decreasing to represents the high and bad quality solutions, repressively. The probability K_{th} ant travels from node i to node j at time t, denoted as *P*, is given by [17]:

$$\rho_{ij} = \begin{cases} \frac{T_{ij}^{\alpha}(t) n_{ij}^{\beta}}{\sum_{j \in N_i^k} T_{ij}^{\alpha} n_{ij}^{\beta}(t)}, j \in N_i^k \\ 0\ , \ \text{otherwise} \end{cases} \tag{4.1}$$

Where N_i^k is a set of non-visited nodes of ant *m*. α, $0 \leq \alpha \leq 1$, and β are two positive parameters, which can control the influence of relative weight of pheromone trailT_{ij}, and the influence of heuristic valuen_{ij}. n_{ij}^{β} defined as the historical value, calculated by [17]:

$$n_{ij}^{\beta} = \frac{1}{d_{ij}} \tag{4.2}$$

Where *dij* is refereed of the distance that is used to reduce the probability to choice a long path.

An ant stops going toward a path when it reach a wrong destination N_i^k is the set of all candidate the neighbour nodes of node *i* and $n_{ij}$is heuristic information. Once all ants complete one iteration, the amount of the pheromone of all the links can be given by following[17]:

$$T_{ij}(t) = (1-\rho) * T_{ij}(t-1) + \rho \sum_{k=1}^{m} \Delta T_{ij}^{k}(t-1) \quad (4.3)$$

Where $T_{ij}(t)$ is the pheromone on the edge (i, j) after modernizing *Ti, j* (*t*−1) is the pheromone before modernizing, k the number of route in the solution. $\rho \in \{0,1\}$ is the evaporation rate of the pheromone while ΔT_{ij}^{k} is the size of pheromone spread which can be calculated by [17]:

$$\Delta T_{ij}^{k} = \begin{cases} \frac{1}{L^{k}} . if ant\ k\ use\ curve(i,j) \in iteration \\ 0, \text{otherwise} \end{cases} \quad (4.4)$$

Where L^k is the length of iteration that generated by ant *kth* route. The E^{lk} here plays an important role of measuring the quality of each ant's solution.

4.5 Simulation Results

The performance of Network Coding-based network with Ant Coding Optimization as routing protocol is evaluated using a dynamic system level simulator. The simulation consists of several iterations and, in each of them; many packets are transmitted by *S*. The bandwidth of each link is randomly varied according to Poisson distribution. Other relevant simulation parameters are summarized in Table 4.1.

Table 4.1: Simulation Parameters

Parameter	Value
Time	1000 sec
B	4
α	1
Probability *P(i,j)*	0.75
Dimension	Selected Randomly
Iteration	200
amount of pheromone T	0.52

4.5.1 Bandwidth Consumption

Figure 4.5 shows the bandwidth consumption as a function of number of active receivers. In this example, the performance of a system using ACO as routing protocol is compared with a system using traditional routing protocol, which has been investigated in [5].

Bandwidth consumption can be defined as the number of links on the transmission paths that are generated by the routing protocol. It can be easily noticed that the bandwidth consumption increases whether network coding based traditional multicast or based ACO is used. However, the figure also demonstrates that by using a network coding based an enhanced performance can be achieved by comparison with a traditional routing protocol.

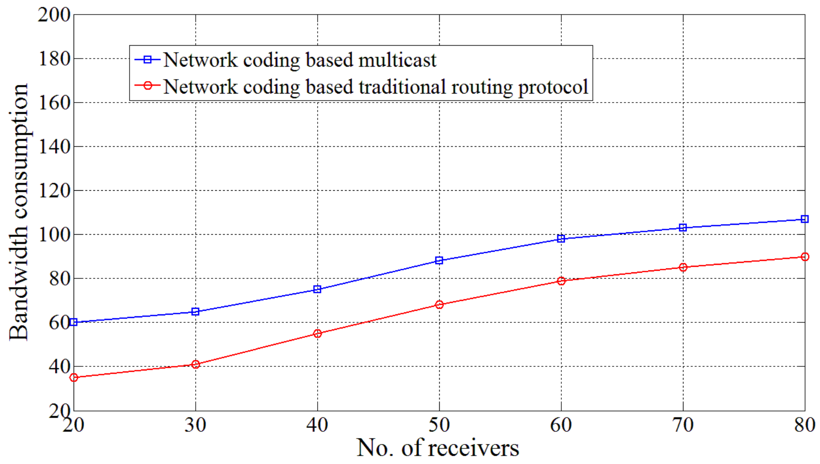

Figure 4.5: Bandwidth consumption [5]

Figure 4.6 presents the relationship between the bandwidth consumption and the number of intermediate nodes for same number of receivers. It is clearly noticed, that less bandwidth consumption can be obtained with ACO routing especially at large number of intermediate nodes.

The due to the fact that larger number of the nodes means more candidates links towards the receivers. The ACO will, indeed, make sure to select the optimum path and hence the bandwidth consumption is reduced.

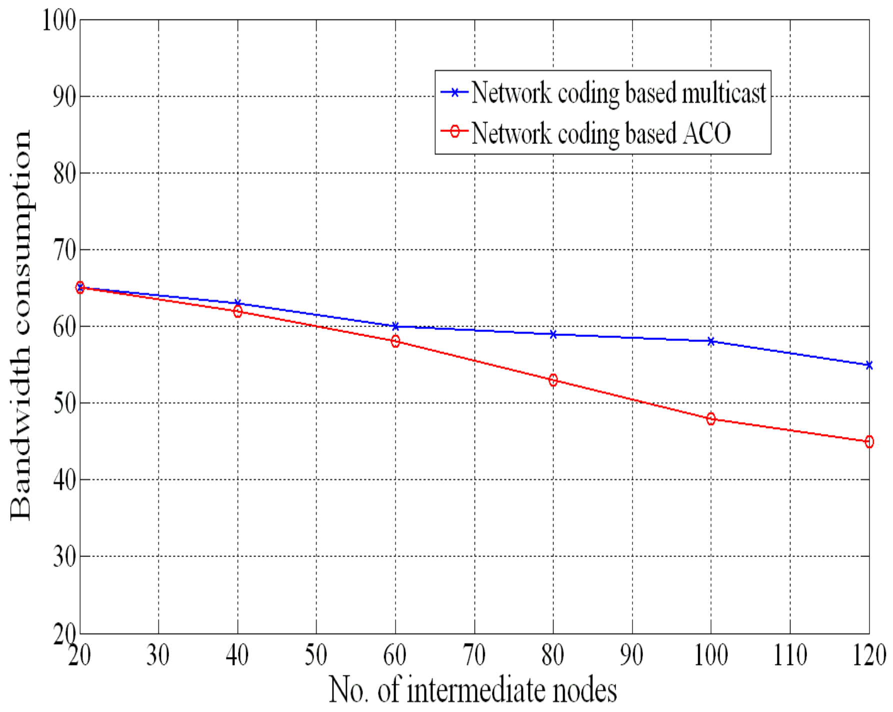

Figure 4.6: ACO and Bandwidth consumption

4.5.2 Delay of Network Coding with ACO

The average packet delay of buffered information as a function of number of node is shown in Figure 4.7 The packet delay can be defined as the time that packet has taken from the source *S* to finial destinations.

It can be seen that with ACO deployment the average packet delay is reduced especially at large number of intermediate nodes compared with the traditional routing protocol.

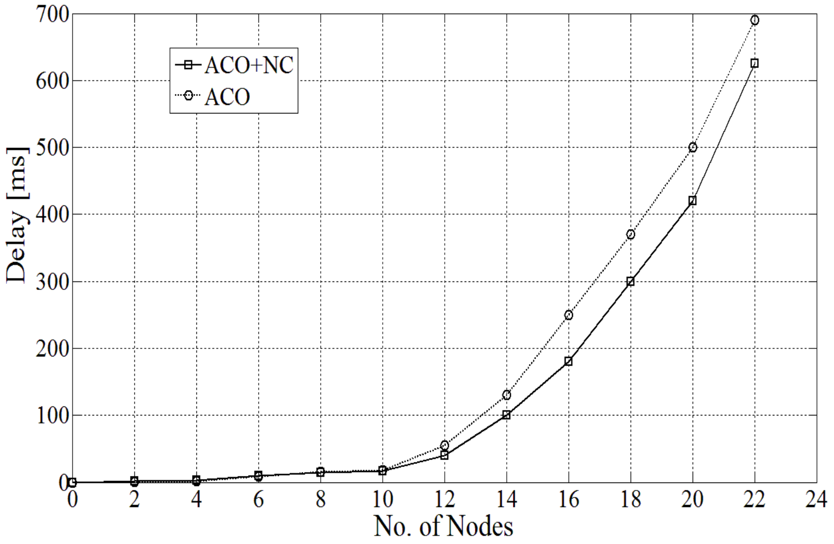

Figure 4.7: Delay vs. number of nodes

This is because with ACO, the shortest path is always selected among other candidate paths. Increasing number of nodes means there is more selections to find the optimum route from the source to destinations and hence the packet delay would be reduced. It can also be noticed that if the number of nodes is small the performance of ACO is approximately the same to that of the traditional routing protocol because there is few candidate paths needs to be optimized.

4.6 Summery

This chapter has presented the system model and simulation results for two scenarios.

In the first scenario, it has studied the performance of butterfly network system that show increase in throughput system and reduce in packet delay when using network-coding technique by combining the packet that transmit from the source at intermediate nodes and delivered in single transmission to destination.

In second scenarios system-level simulator shows that performance of system by combining the network coding technique with ant colony routing can reduced in bandwidth consumption and reduce computation time of sending data more than the traditional routing schemes.

5 Conclusions and Future Research

5.1 Conclusions

In this research, the deployment of Ant Colony Optimization as routing protocol with network coding has been investigated and the performance for a proposed network in term of packet delay and throughput and bandwidth consumption has been presented. The new protocol's formulation depicts the relationships between network coding which helps to approach appropriate transmission and ACO by combining the benefit of ACO algorithm, i.e., selecting the most suitable paths in the network, with Network Coding results in less congestion and a more stable network connection. Routing protocol should be designed to achieve high performance in a network.

Simulation results demonstrated that the proposed algorithm could significantly improve the performance of the network in term of, packet's delay, throughput and bandwidth consumption. First, it has been shown 25% reduction in packet delay can be achieved if ACO was using as routing protocol. That leads to much more improvement in the throughput, about 33%, than the traditional routing protocols in butterfly networks. Additionally, there was 25% gain in the bandwidth consumption by adopting ACO with network coding by comparison with traditional routing protocols. Furthermore, the proposed algorithm that indicate of combining network coding with ant colony optimization can speed up the transmission rate 20% more than the traditional schemes.

5.2 Future Research

Network coding based Ant Colony Optimization has been seen as promising protocol to improve the performance of a butterfly networks.

One possible direction for future work is to adopt the proposed protocol in wireless Ad-hoc based networks. In Ad-hoc networks the receivers, as well as the intermediate nodes, can transfer anywhere, anytime and still stay connected with the rest of group of nodes Ad- hoc is an autonomously self-organised network that does not have fixed communications. In theory, if individual node has approach to the Internet, all other group members should have the potential to stay connected with the Internet. Figure 5.1 shows an example for Ad-hoc network with nodes being located on airplanes, cars, mobile phones or laptops.

Using Ant Colony Optimization in such networks is large challenge in sense of the nodes will always need to calculate the optimum paths due to instability in topology of the Ad-hoc network , The Ant Colony Optimization, thus, need to be modified in order to fit such environment. In addition, nodes in a mobile wireless Ad-hoc network might have limited transmission ranges, some nodes cannot be able to communicate directly with each other and that leads in losing some coding packets. This gives another issue in network coding. In principle, each node should be able of performing network coding as well as routing.

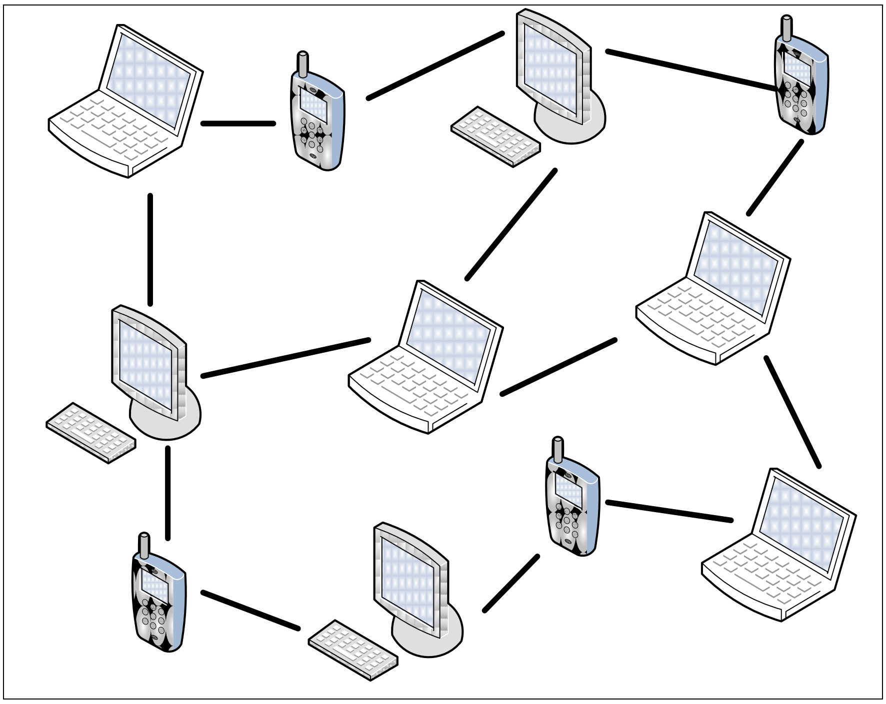

Figure 5.1: Mobile Ad-Hoc Network

Another possible direction for future work is to reduce the complexity of ACO algorithm. Hence, increasing the number of node leads to high computing time that requires calculating the optimum path and hence the implementation of ACO will be difficult in practical. Therefore, designing suboptimum algorithm that trade-off the performance and complexity is essential in this case.

Another possible area for future work is this proposed algorithm could be implemented to additional protocols using different meta-heuristics like particle swarm optimization (PSO) that is a population-based stochastic method for solving uninterrupted and distinct optimization problems. In particle swarm optimization, basics software agents, called *particles*, transfer in the search area of an optimization problem. The position of a particle depicts a candidate solution to the optimization problem at hand. Each particle investigate for proper location in the optimization area by replacing its direction according to rules originally motivate by behavioural of bird gathering that used to solve computational optimization problem[91].

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