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# Applications of Complex Networks and Swarm Intelligence in Cloud Computing

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**ABSTRACT**
Cloud computing infrastructures are cutting-edge platforms that can benefit businesses of any size significantly. For many network types, including wired networks and wireless ad hoc networks, many algorithms have been developed. Swarm intelligence is a modern artificial intelligence discipline that is concerned with the design of multiagent systems with applications. The design paradigm for these systems is fundamentally different from more traditional approaches. Instead of a sophisticated controller that governs the global behavior of the system, the swarm intelligence principle is based on many unsophisticated entities that cooperate in order to exhibit a desired behavior. Complex networks have emerged as a candidate for changing the monotony of collected data about networks. Inside our universe, complex networks can be found everywhere. It is a new multidisciplinary research area that includes engineering, biology, sociology, physics, and economics, as well as linked biological and chemical systems, neural networks, social interacting species, the Internet, and the World Wide Web. Complex networks are essential to human survival. This paper advocates and proves with facts that CN and Swarm Intelligence based algorithm can be effectively used in Cloud Computing for efficient use of resources.

**Keywords –** Cloud Computing, Swarm Intelligence, Complex Networks, Link Prediction, Common Neighbor, Adamic Adar,Data Mining

## I. INTRODUCTION TO CLOUD COMPUTING

Cloud computing is a type of Internet-based network that consists of a lot of cheap, modular, and open standards-based servers. Large numbers of individuals can access a variety of services via clouds, which house enormous amounts of information. In a nutshell, cloud computing is a paradigm where data is permanently saved on servers connected to the Internet and temporarily cached on clients including desktops, media centres, tablet computers, notebooks, wall computers, mobile devices, sensors, displays, etc. Abstraction of the hardware from the service is the most significant feature of a cloud. The Internet is transforming thanks to cloud routing in a similar way to how cloud computing has transformed computers and cyber-infrastructure. The location of routers and switches with the shortest geographic reach is a key component of modern Internet topologies. Because cloud computing is becoming more and more applicable every day. As executives consider moving data and processing to cloud providers, security does actually become a major concern. Reliability, availability, confidentiality, and other key issues are some of the main cloud computing concerns. Each time a data breach occurs in a cloud offering and is reported in the media, these and numerous other issues will unavoidably derail the position of cloud computing. All these security issues are hindering the growth of cloud computing globally.

The illustrations that are frequently used to depict the Internet gave rise to the term "cloud computing." A new method of consuming and delivering IT services is cloud computing. The idea of cloud computing signals a change in perspective among end users who are no longer required to understand the specifics of a certain technology. The supplier oversees every aspect of the service. Services can be consumed by users at a rate determined by their individual needs. This on-demand service is always available. Cloud computing is frequently just a metaphor for the Internet, representing the growing transfer of compute and data resources online. But cloud computing marks a new turning point in the value of network computing, thus there is a distinction.

### Cloud Computing Models

Cloud computing models can be divided into three basic designs, which are shown here and described below.

•Infrastructure-as-a-Service (IAAS): An organisation can outsource the hardware, software, servers, and networking components it needs to run its operations by using this provision model. The equipment belongs to the service provider, who is also in charge of housing, operating, and maintaining it. Usually, the client makes a per-use payment.

•PAAS (Platform-as-a-Service) - In this sort of cloud computing, a platform is made available for use. All stages of the system development life cycle (SDLC) are covered by the services offered by this model, which can also make use of gateway software, online portals, and application programme interfaces (APIs). Because some providers forbid moving customer-created software off the provider's platform, buyers must examine specific solutions carefully.

• SAAS (Software as a Service) - This model is intended to take care of everything and only require the user to rent the software. Usually, the service is offered via a front end or web portal. The corporation pays a per use price even if the end user is free to utilize the service from any location..

## II. COMPLEX NETWORKS

Complex networks have emerged as a candidate for changing the monotony of collected data about networks. Inside our universe, complex networks can be found everywhere. It is a new multidisciplinary research area that includes engineering, biology, sociology, physics, and economics, as well as linked biological and chemical systems, neural networks, social interacting species, the Internet, and the World Wide Web. Complex networks are essential to human survival. A significantly varied allotment of links characterizes complex networks, which is often dispersed by the presence of crucial features such as heftiness. Because there are traits that exist in the network representation of these systems, they deserve the term "complex networks." They have properties that appear as a result of the global topological organization of the organization, and their topological structures cannot be inconsequentially described like in the cases of arbitrary or standard graphs. The Internet is an illustration of a complex network, which can be defined as huge group of interconnected nodes. A node can be whatever thing: a human being, an institute, a computer, a biological cell, etc. Interconnected implies that two nodes may be linked, for example, because two people recognize each other, two organizations trade goods or two computers contain a wire connecting the two of them. In complex networks there are a lot of characteristics that emerge as a consequence of the global organizational structure of the network. For instance, an observable fact known as “small world” is attributed by the existence of relatively small average path length and a relatively high number of triangles in the network

**Link Prediction**

The properties of the nodes and their connections in a complex network are used to create link prediction techniques. Complex networks are everywhere, or when we represent real-world circumstances in terms of networks, we frequently learn new things. The globe appears to be getting smaller with the aid of the internet, and people are fitting more and more connected. It is clear that telephony had a significant part in creating the connected world as we know it, but thanks to the convergence of telecommunication and data networks, it is increasingly challenging to remain disconnected. Being linked has a significant impact on how information is shared. While the first property appears in randomly generated networks, the second “emerges” as a consequence of a characteristic feature of many complex systems in which relations display a high level of transitivity [8]. The link prediction problem in complex networks craft predictions about the future organization of the network. Link prediction methods are developed by using properties of nodes and their relationships in complex network. The topologies of networks are extensively applied to learn the link-prediction problem in recent times. The Common Neighbors is a well-accepted and efficient framework. Numerous variants of Common Neighbors have been proposed to enhance the resolution of contender links.

Basic Link Prediction Methods based on similarity Index where proposed from 2001 to 2003 but Common Neighbour and Adamic Adar Methods stand apart till today in 2021.

| YEAR | LINK PREDICTION TECHNIQUES/METHOD | PROPOSED BY |
|---|---|---|
| 2003 | Adamic Adar | Adamic A &Adar E |
| 2003 | Katz | Liben-Nowell&Kleinberg |

| | | |
|---|---|---|
| 2003 | Jaccard | Liben-Nowell and Kleinberg |
| 2002 | Hub Promoted | Ravasz et al. |
| 2001 | Preferential Attachment Index[40] | Newman |
| 2001 | Common Neighbor Index[40] | Newman |

Table1: Chronology of Link Prediction Methods from CN to AA [19]

## III. SWARM INTELLIGENCE

Swarm intelligence is a modern artificial intelligence discipline that is concerned with the design of multiagent systems with applications, e.g., in optimization and in robotics. The design paradigm for these systems is fundamentally different from more traditional approaches. Instead of a sophisticated controller that governs the global behavior of the system, the swarm intelligence principle is based on many unsophisticated entities that cooperate in order to exhibit a desired behavior. Inspiration for the design of these systems is taken from the collective behavior of social insects such as ants, termites, bees, and wasps, as well as from the behavior of other animal societies such as flocks of birds or schools of fish.

Even though the single members of these societies are unsophisticated individuals, they are able to achieve complex tasks in cooperation. Coordinated behavior emerges from relatively simple actions or interactions between the individuals. Moreover, engineers are increasingly interested in this kind of swarm behavior since the resulting “swarm intelligence” can be applied in optimization for ex. in telecommunicate systems, robotics, traffic patterns in transportation systems and military applications.Swarm intelligence is the emergent collective intelligence of groups of simple autonomous agents. Here, an autonomous agent is a subsystem that interacts with its environment, which probably consists of other agents, but acts relatively independently from all other agents. The autonomous agent does not follow commands from a leader. For example, for a bird to participate in a flock, it only adjusts its movements to coordinate with the movements of its flock mates, mainly its neighbours that are close to it in the flock. A bird in a flock simply tries to stay close to its neighbours, but avoid collisions with them. Each bird does not take commands from a leader bird since there is no leader bird. Any bird can fly in the front, center and back in the swarm. Swarm behavior helps birds take advantage of several things including protection from **predators** and searching for food.

**Principles of the collective behavior**

The main principles of the collective behaviorare:

- **Homogeneity:** Every bird in flock has the same behavior model. The flock moves without a leader, even though temporary leaders seem to appear.
- **Locality:** The motion of each bird is only influenced by its nearest flock mates. Vision is considered to be the most important senses for flock organization.
- **Collision Avoidance:** Avoid with nearby flock mates.
- **Velocity Matching :** Attempt to match velocity with nearby flock mates.
- **Flock Centering:** Attempt to stay close to nearby flock mates.

## IV. COMPLEX NETWORKS AND SWARM INTELLIGENCE IN CLOUD COMPUTING

Recently, there has been a lot of interest in using swarm intelligence to address the problem of adaptive routing in telecommunications networks. Modern platforms like cloud computing infrastructures may greatly help organisations of all sizes. They can help firms utilise their investments in IT hardware and software more effectively and hasten the adoption of new technology. Numerous algorithms have been created for numerous network types, including wired networks and wireless ad hoc networks. A candidate for breaking up the monotony of network data collection is complex networks. An essential tool for accelerating computing is cloud computing. The selection of nodes as servers in such systems that carry out users' actions has a significant impact on how well they perform.the following link prediction techniques can be efficiently used in Cloud Computing:

| | |
|---|---|
| Adamic Adar | Adamic A &Adar E |
| Preferential Attachment Index[40] | Newman |
| Common Neighbor Index[40] | Newman |

Modern network research, however, may demonstrate that while most nodes in real networks are only moderately connected, some nodes do have extremely high connection (hubs). From biological to social networks, many genuine networks exhibit these power-law (scale-free) properties.Due to the recent general availability of vast amounts of network data, network analysis has seen a significant uptick. Real networks were traditionally thought to have a majority of nodes with roughly the same amount of connections on average.Usually, random graphs are used to mimic this.

## CONCLUSION

Numerous algorithms have been created for numerous network types, including wired networks and wireless ad hoc networks. A candidate for breaking up the monotony of network data collection is complex networks. Swarm intelligence is a modern artificial intelligence discipline that is concerned with the design of multiagent systems with applications, e.g., in optimization and in robotics. An essential tool for accelerating computing is cloud computing. Human survival depends on complex networks. This paper advocates and substantiates the usage of CN and Swarm Intelligence-based algorithms in cloud computing for effective resource use.

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