Int. J. Advanced Networking and Applications
Volume: 16 Issue: 03 Pages: 6-11 (2024) ISSN: 0975-0290

Complex Event Processing and Software Defined Network based Fog Computing

Mr. Sarkarsinha H. Rajput, Research Scholar
Department of Computer Engineering, SSBT's COET, Bambhori, Jalgaon (M.S.)
Email: bs.rajput26@gmail.com
Dr. Manoj E. Patil, Head & Asso.Prof.
Department of Computer Engineering, SSBT's COET, Bambhori, Jalgaon (M.S.)
Email: mepatil@gmail.com

ABSTRACT

Smart Cities projects necessitate data processing without depending on complex data processing methods that add unnecessary complexity and latency to any computation or decision. Smart City projects necessitate great service quality and low maintenance costs. Transmitting processed data to a distant cloud environment will not be useful for time-based applications so in order to achieve the latency it is always better to do the processing of information at the edge level in fog computing architecture. Based on data which is acquired by the data sources, fog computing can detect the different pattern of behavior of system in real time. A Complex Event Processing (CEP) engine provides the intelligence required for data processing. For further feasibility, the fog computing concept and Software Defined Network can be used to execute edge level processing. There is lack of mechanism in the Fog Computing architecture that permits the analysis to be diverted in the event of overloading when Complex Event Processing (CEP) engine is applied in the fog node. Software Defined Network is one of the intelligent approaches for the use of load balancing between the different data processing nodes. The top layer of Software Defined Network has the feature of load balancing. We can assess the Software Defined Network in the data processing node, which allows for distributed analysis in order to enhance edge and core performance.

Keywords **- Complex Event Processing, Core level, Edge level, Fog computing, Software Defined Network.**

Date of Submission: Date of Acceptance:

1. INTRODUCTION

As a result of the massive number of gadgets being launched over the internet, we are now creating enormous amounts of data. To use various IoT systems in smart cities, there is a need to deploy a maximum number of IoT devices, which result in a tremendous data flow that requires access to cloud services for processing. [1, 2]. Data processing architecture has changed from a centralized paradigm to a distributed paradigm, or from cloud computing, which is a centralized paradigm, to fog computing, which is a distributed paradigm, in order to address time-based constraints [3]. Basically, the fog computing architecture is nothing but an enhancement of cloud computing architecture, which retains data at the edge level before its transferring it to the core level or cloud. [1, 4, 5].

Fog computing is the new technology that will do the replacement of cloud computing. Edge level in the strategy of fog computing consists of a different variety of devices connected by using sensors, smartphones, single-board computers, and other gadgets. Which are placed at different locations from which data is transferred for processing at fog level and then for further processing it send to the cloud platform. Cloud-based data centres make up the core level in the fog computing approach. There are a variety of open-source platforms for stream processing in distributed way that offer varying levels of performance and are suitable to specific applications. For sophisticated processing, complex event processing is used in the fog node which is at edge level of fog computing [1]. CEP stands for Complex Event Processing, and it is a current paradigm for data processing in the form of events. CEP is concerned with what has recently occurred or will occur in the future. An event is an occurrence, occurrence, or changes in the current state of situation. Event could be a sensor data, energy use, change notification of a price, or some other kind of information. An event is also considered as something that didn't happen [6]. The network control and data sections are separated in a Software Defined Network (SDN). SDN has demonstrated considerable advantages over traditional non-SDN networks in a variety of ways [7]. Different load balancing strategies [8] are provided by SDN to efficiently balance the load between different data processing nodes. Fog's performance is made up of a number of essential metrics, including latency, bandwidth, connectivity, and storage security. In the fog node, it is appropriate to test the Software Defined Network approach, which facilitates the analysis, is redirected in the event of fog node get overload [5].

2. Literature Survey

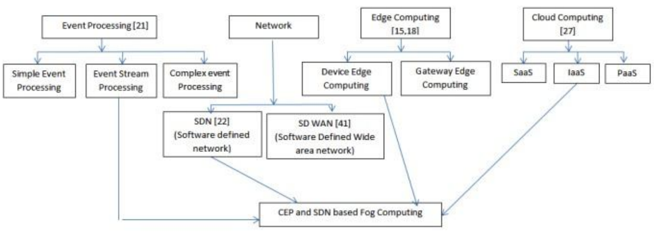

Fig.1. Approaches for Fog Computing

In the structure of literature survey, we have studied the different technologies such as fog computing, event processing techniques, edge level technology, software defined network and cloud computing in order to combine these things to design the effective fog computing platform to provide the minimum latency services.

2.1 Fog Computing Overview

It bridges the gap existing between Internet of Things devices and the cloud by allowing computation, networking, storage, and data management. The latency of delivering and responding to ultimate consumers is decreased as well as access to the core level when computation and processing of data are near to data sources [9, 10]. The authors of [11] gave details of the existing literature in fog computing, focusing on distinct fog designs and techniques. They also demonstrate that fog computing is a very new technology. The authors [12] give the full detailed assessment of all latest advances in the fog based network topologies, as well as a variety of fog computing network applications.

The author [13] concentrated on the different kind of connectivity and configuration of devices of fog computing and outlined the fundamental characteristics needed to construct the infrastructure for IoT-type applications, such as those for smart cities. They continue by going over the solutions that have been proposed to deal with the fog computing problems in light of the growth of smart city infrastructure.

The authors in [14] examine fog-assisted IoT applications in greater depth, explore fog computing security services and different privacy challenges and analyze viable solutions for resolving privacy and security issues in fog based IoT systems.

2.2 What is Edge?

In the IoT [15,16], The word "edge" describes a local network that has several sensors and Internet of Things devices deployed on it. As opposed to IoT nodes, the edge describes the initial point of contact between IoT devices such as gateways or access points of WiFi. Mist computing [17] is also a type of computing that uses the IoT devices themselves to perform computations.

2.3 Edge Computing

Edge computing is located close to Internet of Things devices and at the edge of the network. It does not imply that IoT devices contain the edge level; rather, it just means that it is near them. It's critical to remember that in an IoT network, the edge is only one step away from end devices [15]. The fog and edge computing therefore go hand in hand to make this a practical solution. Due to the IoT devices, a huge amount of data is generated, which is time and security sensitive. According to Open Edge Computing, edge computing refers to processing which is done at the edge level of network edge using fog computing, edge computing and small data centres next to users [18]. To give readers a thorough understanding of the subject, the writers [19] concentrated on edge computing architecture design and system administration. They also compare and contrast a number of related computing ideas, such as mobile grid computing, mobile crowd computing, and peer-to-peer computing, in order to explain fog and edge computing [15].

2.4 Event Processing

Event Processing is a processing system of data that processes event data in real time. EP is a concept in which flow of events are studied in order to extract relevant situation from real world happenings.

There are a variety of real world applications that involve the processing of data that is coming in from outside the system [20].The event is said to be complex which is generated from a different events by combining derivation functions. Such a complicated event can represent information contained in a group of connected events [21].

Tools used by Complex Event processing**:** Stream Explore, IBM Streams, Oracle Stream Analytics, Microsoft Azure Stream Analytics, Amazon Kinesis Analytics, Apache Spark, Apache Flink, Apache Samza, Apache Storm, Hadoop or MapReduce, etc.

2.5 Software Defined Network (SDN)

SDN (software-defined networks) is an innovation of networking in which all regulating and administrative tasks are centralized in a single controller, separating the data section from the control plane [22].

Table 1. Major Challenges of SDN

Paper Title	Author	Year	Challenges
A distributed control plane for OpenFlow.	Tootoonchian A, Ganjali Y. HyperFlow	2010	SDN can scale with Hyperflow because it logically centralises and physically distributes network overhead throughout the control plane.
Enhancing responsiveness and scalability for OpenFlow networks via control-message quenching.	Luo T, Tan H-P, Quan P, Law YW, Jin J.	2012	Lowering the delay of flow establishment and raising network throughput to enhance the responsiveness of SDN controllers and network scalability.
Devolving IEEE 802.1X authentication capability to data plane in software defined networking (SDN) architecture.	Benzekki K, El Fergougui A, ElBelrhiti ElAlaoui A.	2012	Enhancing performance and access control while decreasing the heavy load on the SDN controller.

A system for scalable OpenFlow control, Rice Univ., Houston, TX, USA, Tech. Rep. TR10-08, Dec. 2010.	Cai Z, Cox AL, Ng TE. Maestro:	2010	Utilizing multicores, parallel processing, and many threads to increase the controller's capability in order to implement a scalable SDN.
Towards elastic distributed SDN controller. Second ACM SIGCOMM Workshop on Hot Topics in Software Defined Networking.	Dixit A, Hao F, Mukherjee S, Lakshman T, Kompella R.	2013	Addressing the issue of load imbalance to give SDN elasticity and load-balancing.
ONOS: towards an open, distributed SDN OS. Proceedings of the Third Workshop on Hot Topics in Software Defined Networking.	Berde P, Gerola M, Hart J, et al.	2014	Enhancing SDN's performance and scalability to meet the demands of large-scale networks.
An efficient elastic distributed SDN control plane. Proceedings of the Third Workshop on Hot Topics in Software Defined Networking, ser.	Krishnamurthy A, Chandrabose SP, Gember Jacobson A. Pratyaastha:	2014	Utilizing SDN to improve performance while lowering resource consumption and intercontroller communication.
On the cascading failures of multi-controllers in software defined networks. Network Protocols (ICNP), Conference on. IEEE, 2013, pp. 1–2.	Yao G, Bi J, Guo L.	2013	Recognizing the danger that failures pose to the dependability of SDN networks and offering a model of these failures as a means of prevention.
Detour planning for fast and reliable failure recovery in SDN with OpenState.	Capone A, Cascone C, Nguyen AQ, Sansò B.	2014	Assessing SDN's potential for dependable communication.
Reliability and scalability issues in software defined network frameworks. Second GENI. IEEE. 2013, pp. 102–103.	Guan X, Choi BY, Song S.	2013	Due to the complex nature of its software and hardware components, SDN reliability is challenging to analyze.
Security in Software Defined Networks: A Survey	Ijaz Ahmad et.al.	2015	SDN is susceptible to assaults because of its centralized control.
Orchestration in Fog Computing: A Comprehensive Survey	Breno Costa et.al.	2022	Sophisticated tools and frameworks are necessary for the efficient administration and orchestration of SDN resources in a variety of scenarios.
A Survey on P4 Challenges in Software Defined Networks: P4 Programming	Bhargavi Goswami et.al.	2023	The specific knowledge needed to develop SDN applications can narrow the pool of available talent and lengthen the development time.

2.6 Telemetry Protocol

Telemetry is the most crucial component when creating an effective Internet of things network with quality of service for fog computing. Numerous telemetry protocols exist, including the Message Queue Telemetry Transport (MQTT), Hypertext Transfer Protocol (HTTP), Advanced Message Queuing Protocol (AMQP) and the Constrained Application Protocol (CoAP). There is detail comparison is carried out in [23] and conclude that all these protocols have their advantages according to given conditions but according to [23], Message Queue Telemetry Transport is protocol of lightweight category and it is also an protocol of machine to machine category which is used in different components of fog computing and it is most used protocol [24] .Message Queue Telemetry Transport (MQTT) uses less bandwidth and flexible for the levels of latency. MQTT uses star topology in which central node is used as server [5].

2.7 Cloud Computing

Processing, storage, and networking infrastructure have been built on a platform specifically designed for cloud computing. The NIST defines cloud computing as a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources [15, 25]. Cloud data centres provide easily accessed virtualized resources that may be dynamically changed to suit the requirements of any scalable application. For cloud services with a pricing scheme, this is helpful [26]. Using the cost model, which only costs for what is used, users can simply obtain data management services and remote computing resources. Application developers get access to these services dependent on the specifications of the apps they are creating. Cloud users can access to IT infrastructures for networking, data processing and this credit goes to infrastructure as a service [27].

Private, community, hybrid, and public cloud deployments fall under one of four categories [25]. Private clouds are used by a single entity and offer the highest level of flexibility and privacy. Private clouds are an option for businesses looking for application infrastructure. Hybrid clouds, to put it simply, are a synthesis of the several cloud forms previously discussed. It gives customers more control over virtualized infrastructure, and they use standardized or proprietary technology to combine the features of several types of cloud installations [28].

2.8 Comparative analysis between CEP and SDN for fog computing

CEP (Complex Event Processing)	SDN (Software Defined Network)
Detection, processing, architectural design, and reaction mechanisms are some of the crucial aspects in implementingComplex Event Processing (CEP) in fog computing.	Separating the control and data planes in fog computing allows for dynamic network management and optimization at the edge. This is known as Software Defined Networking, or SDN.
Architectural Design: fog nodes, Cloud integration and event sources [29].	Architectural Design: Fog nodes, SDN Controller and Data Flow Management [30].
Event Detection: Events, Data Collection and Initial Filtering [31].	Network Abstraction: Control Plane, Data Plane [32].
Event Processing Framework: CEP Engine, Pattern Recognition and Temporal Analysis [33].	Dynamic Resource Allocation: Traffic Management and Resource Optimization [34].
Security and Privacy: Data Encryption and Access Control [35].	Security and Privacy: Network Security and Access Control [36].
Analytics and Response: Real-Time Processing, Trigger Actions and Feedback Mechanism [37].	Monitoring and Analytics: Network Monitoring and Data Analytics [38].
Scalability and Fault Tolerance: Load Balancing and Redundancy [39].	Interoperability: Integration with Existing Networks and Standard Protocols [40].
Use Case (Smart Agriculture): Temperature and soil moisture can be tracked by sensors in smart agriculture. In order to identify irrigation conditions, a fog computing architecture can interpret this data in real-time. Temp and moisture sensors in the soil are the event sources. Events are detected by using moisture levels as a trigger. Data streams can be analyzed through event processing by using a CEP engine. In response, automate irrigation systems in accordance with conditions that have been analyzed.	Use case (Smart Transportation): SDN has the ability to control data flows from a variety of sensors and cameras at intersections and on roads in smart transportation systems. Traffic sensors and cameras are examples of event sources. SDN govern: To govern data pathways from sensors to processing nodes, use an SDN controller. Utilize dynamic routing to optimize data routing in response to current traffic conditions in order to decrease congestion and speed up response times.
Conclusion By using CEP in fog computing, real-time data processing is improved, allowing for swift decisions and insights.	Conclusion By implementing SDN in fog computing, network resources may be managed in a flexible and effective manner, improving edge data processing capabilities.

3. CONCLUSION

Many various organizations, including those in healthcare, industry, government, energy, retail, education, transportation, and smart cities, benefit from the Internet of Things (IoT) accelerated digital transformation. This is the count of connected devices provided by the Internet of Things. IoT networks are growing as more companies and individuals install IoT devices on a daily basis. It is anticipated that the Internet of Things (IoT) will link crores of people and different devices while offering us some fascinating benefits. The platforms for processing heterogeneous data provided by a variety of IoT devices, which is always time-based processing, are fog computing. The data analysis pattern for the specified events in the fog node is sped up by complex event processing technology. The real challenge is in keeping the service standards compatible with modern network and telecommunications requirements, in terms of fault management, detection, and recovery, in defending against unauthorized access and denial of service attacks, high throughput, extremely low latency, software updates, and patches. Complex event processing (CEP) and Software Defined Network (SDN) based fog computing approach, can be helpful for data processing and load balancing among the fog nodes at the edge level to improve fog computing's performance from all angles. Elasticity and scalability are other important ideas, but those might be goals when building networks with high availability and low performance with low latencies.

REFERENCES

1. Giovanny Mondragon-Ruiz, Alonso TenorioTrigoso, Manuel Castillo-Cara, Blanca Caminerand Carmen Carrión (2021), An experimental study of fog and cloud computing in CEP-based Real-Time IoT applications, *Journal of Cloud Computing: Advances, Systems and Applications*, 2021.
2. Sarkar S, Chatterjee S, Misra S ,Assessment of the Suitability of Fog Computing in the Context of Internet of Things, *IEEE Trans Cloud Computation*,2018.
3. Xiong Z, Feng S, Wang W, Niyato D, Wang P, Han Z,"Cloud/fog computing resource management and pricing for block chain networks, *IEEE Internet Things* , 2018.
4. Rahmani Et.al., Fog computing in the internet of things: Intelligence at the edge", *Springer International Publishing,* 2017.
5. Barik RK, Dubey H, Sasane SA, Lenka RK,Misra C, Borthakur D, Constant N, Mishra BSP, Das H, Mankodiya K, Fog assisted cloud computing in era of big data and internet-of-things: systems, architectures, and applications in Cloud Computing for Optimization: Foundations, Applications, and Challenges, *Studies in Big Data, Volume 39*, Springer,Cham.,2018.
6. Andreas Wagner, DarkoAnicic, Roland Stuhmer, NenadStojanovic, Andreas Harth, and Rudi Studer, "Linked Data and Complex Event Processing for the Smart Energy Grid".
7. Kamal Benzekki ,Abdeslam El Fergougui and Abdelbaki Elbelrhiti Elalaoui, Software-defined networking (SDN): a survey, security and communication networks, *Wiley Online Library,2017.*
8. Mosab Hamdan, Entisar Hassan, Ahmed Abdelaziz, Abdallah Elhigazi, Bushra Mohammed, Suleman Khan, Athanasios V. Vasilakos, M.N. Marsono, A comprehensive survey of load balancing techniques in software-defined network, *Journal of Network and Computer Applications,* 2020.
9. Bonomi F, Milito R, Zhu J, Addepalli S., Fog computing and its role in the internet of things, MCC workshop on Mobile cloud computing. ACM, *Helsinki Proceedings of the first edition*, 2012.
10. Wu C, Li W, Wang L, Zomaya A (2018) ,"Hybrid Evolutionary Scheduling for Energy efficient Fog enhanced Internet of Things", *IEEE Trans Cloud Comput*., 2018.
11. C. Mouradian , D. Naboulsi , S. Yangui , R.H. Glitho , M.J. Morrow , P.A. Polakos , A comprehensive survey on fog computing: state-of-the-art and research challenges, *IEEE Commun. Surv. Tutor*, 2018, 416 to 464 .
12. M. Mukherjee, L. Shu , D. Wang,Survey of fog computing: fundamental, network applications, and research challenges, *IEEE 20* (3),2018, 1826 to 1857.
13. C. Perera , Y. Qin , J.C. Estrella , S. Reiff Marganiec , A.V. Vasilakos, Fog Computing for Sustainable Smart Cities - A survey", *ACM Comput. Surv.(CSUR)*,2017.
14. J. Ni, K. Zhang, X. Lin, X. Shen, Securing fog computing for internet of things applications: challenges and solutions, *IEEE Commun. Surv. Tutor.* , 2018, 601 to 628 .
15. Ashkan Yousefpour et.al. ,All One Needs to Know about Fog Computing and Related Edge Computing Paradigms- A Complete Survey, 2019.
16. https://www.ge.com/ digital/blog/what-edge-computing , *Blog, General Electric.*
17. http://rethinkresearch.biz/articles/cisco-pushes-iot-analytics-extreme-edge-mist-computing-2 , *Blog, ethink Research.*
18. http://openedgecomputing.org/about.html , *Technical Report, Open Edge Computing.*
19. C. Li , Y. Xue , J. Wang , W. Zhang , T. Li, Edge-oriented computing paradigms: a survey on architecture design and system management, *ACM Comput. Surv. (CSUR) 51* (2),2018, 39:1–39:34.
20. Gianpaolo Cugola and Alessandro Margara.(2012) ,Processing Flows of Information: From Data Stream to Complex Event Processing, *ACM Comput. Surv. 44*,2012.
21. Opher Etzion.,Complex Event. In Encyclopedia of Database Systems, *LING LIU and M.TAMER ZSU (Eds.). Springer US*, 2009, 411–412.
22. Amirah Alomari, *SDN-Based Fog Computing*.
23. Naik N, Choice of effective messaging protocols for IoT systems: MQTT, CoAP, AMQP and HTTP,*IEEE International Systems Engineering Symposium (ISSE). IEEE*, 2017, 1–7.
24. MQTT: *The Standard for IoT Messaging*, 2021.
25. P. Mell, T. Grance, et al., The Nist Definition of Cloud Computing, 2011..
26. L.M. Vaquero , L. Rodero-Merino , J. Caceres , M. Lindner , A break in the clouds: towards a cloud definition, *ACM SIGCOMM Comput. Commun. Rev. 39* (1), 2008, 50–55
27. T. Dillon, C. Wu, E. Chang , Cloud computing: issues and challenges", *IEEE International Conference on Advanced Information Networking and Applications*, 2010, PP 27 to 33 .
28. B. Sotomayor, R.S. Montero, I.M. Llorente, I. Foster, Virtual infrastructure management in private and hybrid clouds, 2009.
29. Bonomi, F., Milito, R., Natarajan, P., & Zhu, J.,Fog Computing and Its Role in the Internet of Things,

Proceedings of the 1st Edition of the MCC Workshop on Mobile Cloud Computing, 2012.
30. Bonomi, F., Milito, R., Natarajan, P., & Zhu, J.,Fog Computing and Its Role in the Internet of Things, *Proceedings of the 1st Edition of the MCC Workshop on Mobile Cloud Computing*, 2012.
31. D. C. G. Oliveira, P. R. L. S. Costa, L. F. M. de Oliveira, & M. C. Pereira. (2021). Event detection in IoT data streams: a survey, *Journal of Network and Computer Applications*, 2021.
32. Kreutz, D., Ramos, F. M., Verissimo, P. E., Freitas, F. N., & Oliveira, R., Software-Defined Networking: A Comprehensive Survey, *IEEE Communications Surveys & Tutorials*,2015.
33. O.T. S. Mak, A. W. T. Chan, H. J. Lee, & A. C. C. Tsang., A Survey of Complex Event Processing in the Internet of Things, *IEEE Internet of Things Journal*,2020.
34. Zhang, Y., & Zhao, Y. , Dynamic resource allocation in fog computing environments, *IEEE Access*,2016.
35. S. M. Y. Razak, K. B. K. Rehman, & S. K. S. Rahman, Security and privacy in fog computing: A survey, *Journal of Network and Computer Applications*, 2019.
36. K. W. Wong, R. R. D. O. C. C. S. R. F. Ma, & W. P. H. Lee., Security and Privacy in Software-Defined Networking: A Survey, *IEEE Communications Surveys & Tutorials*,2017.
37. P. P. Jayaraman, M. A. M. Alavi, A. J. D. Hall, & A. D. B. Lewis., Real-Time Event Processing in Fog Computing for IoT Applications, *IEEE Transactions on Cloud Computing*, 2018.
38. Heller, B., Sherwood, R., & McKeown, N., Building a Programmable Switch from OpenFlow, *Proceedings of the 2010 ACM SIGCOMM Workshop on Hot Topics in Networking*, 2010.
39. S. K. Gupta, & D. Ghosh, Scalable and fault-tolerant complex event processing in fog computing, *Future Generation Computer Systems*, 2017.
40. Hu, F., Hwang, K., & Yang, Y., Interoperability in Fog Computing: A Survey, *IEEE Internet of Things Journal*, 2018.
41. The SD-WAN Market: 2021." *Gartner Report*.

Biographies and Photographs

Mr. Sarkarsinha H. Rajput, completed B.E. from D. N. Patel College of Engineering, Shahada Dist: Nandurbar (M.S.) and M.E. from SSBT’s College of Engineering and Technology, Bambhori, Jalgaon (M.S.). He is working as Assistant Professor in SSBT’s College of Engineering and Technology since 2009. He is pursuing Ph.D. in Computer Science & Engineering from Kavayitri Bahinabai Chaudhari North Maharashtra University, Jalgaon (M.S.). His areas of interest are Fog Computing, Cloud Computing, Machine Learning.

Dr. Manoj Eknath Patil has completed PhD degree in Computer Science & Engineering from Jodhpur National University, Jodhpur, Rajasthan. Currently he is working as Associate Professor & Head, Department of Computer Engineering, SSBT’s College of Engineering & Technology, Jalgaon (M.S.) and recognized PhD Guide in Kavayitri Bahinabai Chaudhari North Maharashtra University, Jalgaon (M.S.). He has 39 research papers in reputed peer reviewed journals in addition to 20 papers in International Conferences to his credit. He is Life Member of ISTE. His research interests are Wireless Sensor Networks, Web Security, Cloud Computing, Fog Computing, Machine Learning, Blockchain.