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Resource Allocation in Fog Computing: A Review

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Abstract:
Coupled with resource retrained system and devices, Internet of things network requires effective utilization of Fog Computing system. With increasing demand and requirements for enhancing the performance, fog computing scenario requires increased output, less latency, greater performance etc. This review takes the concept of fog computing one step further by reviewing available literature on the components of fog computing to determine the effective outcomes for different settings and management of the network consideration. Contributing to the development appropriate settings and management of the cloud based support, necessary analysis has been carried out in this review. Systematic analysis on the development of fog computing such as system model has been analyzed. To review the prospects and development of fog computing, necessary relationships have been established such as fog computing, fog – cloud computing and fog – fog computing. Based on the learning of the research, future direction for the research has been suggested as well.

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1. Introduction

FOG computing is termed as the complex distributed computer network and infrastructure for enabling IOT or Internet of Thing (Zebari et al., 2019; Zeebaree, et al., 2020; Zhang et al., 2017). Users can extend and utilize data management locally serving appropriate linking methods which also works as the extension of cloud computing (Fernández-Caramés et al., 2018; Zeebaree et al., 2020; Zeebaree et al., 2020). Usage of applicable information sensors, global positioning system or GPS, identification of radio frequency technology to analyse and collect real time information of objects or processes, is terms as Internet of Things (Haji et al., 2020; Shukur et al., 2020; Wollschlaeger et al., 2017). The fog computing paradigm is influenced by rapidly increasing demand for ultra-high reliability and need for low latency. The concept of fog computing relies on the appropriation of network function virtualization process networking and software defined networking pathing enabling the architecture to overcome the limitations of traditional way of mapping (Lavanya et al., 2017; Zebari et al., 2018; Zeebaree, et al., 2020). Unlike the traditional cloud computing system, the concept of edge computing provides improved leverage and functionality for the users (Alzakholi et al., 2020; Liu et al., 2017; Zeebaree et al., 2019). Some of the advantages over the traditional centralized terminal based cloud computing are enhanced data offloading services, shorter response time, improved engagement of the users and instantaneous support management.

2. FOG COMPUTING

Fog Computing is considered as an emerging complex paradigm that connects the cloud sources with a range of IoT (Internet of Things) applications and processes while reducing network traffic, improving network and performance experience, by enabling wide spectra of services such as integrated distribution storage facility, networking functions and computing control (Li et al., 2013; Nguyen et al., 2018; Zeebaree, et al., 2020). FC is viewed as the key solution to meet the challenges of low latency applications and processes, and systems such as 5G networks, embedded AI (Artificial Intelligence), tactile internet, augmented reality applications etc. (Abdullah et al., 2020; Dino et al., 2020; Luong et al., 2017). Though there is immense potential for FC in present day world, FC still remains at the infancy stage in many considerations and many vital challenges and scopes need to be addressed for the development of wide ranging applications and facilities (Liu et al., 2017). In a standard fog computing paradigm, a resource pool constituting of different forms of Fog Nodes (FN) are shared among the service users. In this FN setup, one or multiple FN or computing units including micro data centers, edge clouds, enterprises, servers, etc. are setup in organised manner (Dino et al., 2020; Liu et al., 2019; Mahmood et al., 2021). Ensuring required services to the end users remains a challenge for the fog computing providers at present time. For ensuring enhanced capability and service orientation, relevant measures and support management are required (Dino et al., 2020; Madni et al., 2016; Sallow et al., 2020)[10]. Fog computing has also several applications within the context of Internet of Vehicles (IoV) (Ma et al., 2019). Implementation of complex aspects of the computational offloading and traditional offloading decisions in the resource allocation remain questionable in game theoretic assessment (Madni et al., 2017; Rashid et al., 2018; Sadeeq et al., 2018). Theoretical analysis of Fog computing will be considered to enhance the understanding of the components of FC.

2.1. *System Models*

In this section, system models for fog computing such as network model, computation model for analysis and communication model will be introduced. Considering a generalized system for the relationship between fog computing and IoT applications, system theory can be used (Chiang & Zhang, 2016; Rashid et al., 2019; Zeebaree, et al., 2019). Considering the challenges and opportunities for the fog computing assessment, dedicated FNs and used for the

development of the IoT environment. To analyse different components of fog enabled IoT system, FNs can be used to determine the implications and relationship in the fog computing environment (Dharaskar & Tripathi, n.d.; Haji et al., 2020.; Yaseen and Zebari, 2011). Based on the requirement of the application, either network, communication or computation model can be used (Nguyen & Pham, 2018; Rashid et al., 2019; Saleem et al., 2020).

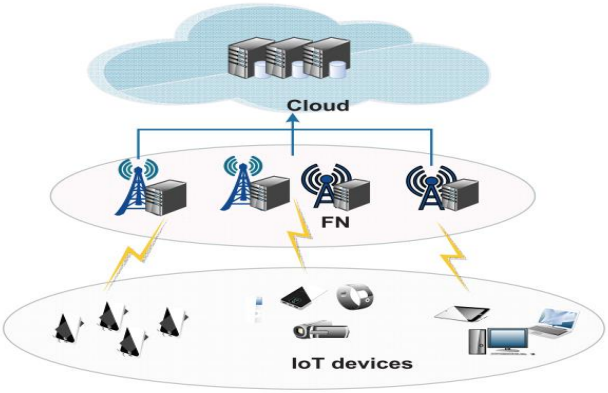

Fig. 1. System model for Fog Computing

Required processes for enabling the fog computing assessment, network model can be determined for further evaluation (Ahmed & Abduallah, 2017; Ni et al., 2017). Based on the proposition of the fog computing setting, different sets of resources and capabilities such as fog layer interpretation, resource selector, processing performance and evaluation, history analyzer, resource selector, task scheduler, IoT devices allocation and management etc. can be addressed. However, these aspects can be interpreted to comply with the specific requirements of fog computing setting (Nguyen et al., 2018; Salih et al., 2020).

2.2. Resource Allocation

In computing system, the Cloud-Fog environmental paradigm is dynamic and complex in nature (Bonomi et al., 2012), as a result, resource allocation becomes challenging for the providers. Prediction based approach to analyse the required resources for FC system has been explored (Aazam & Huh, 2015). In this approach, the system for relinquish probability has been used. Aazam *et al.* proposed that probability for held resources by different individuals can be used for the future prediction of different loading conditions. In this case, if the load is appropriated accurately, the outcome can be calculated effectively. Deng *et al.* worked with an allocation approach primarily for distributing the workload within the scenario of cloud and fog hybrid systems. Analysing the difference of delay and power consumption lead the calculation of resource distribution effectively (Deng et al., 2015). For different cloud and fog relationship and architecture, joint resource allocation model can be used (Do et al., 2015). These models only predict the outcomes for different approaches taken for the appropriation for different FC applications. Contributing to the development of the FC applications and determination of required resources can be used for further evaluation. Resource allocation for dealing with the specific needs of the FC setting, will be organized to achieve the targets of the overall FC environment. Resource allocation process to comply with the network delay and low latency management can be improved by effective utilization of the resource capabilities and addressing the system requirements effectively.

3. Literature Review

Increasing demand and requirements for the aspects of Quality of user experience has influenced the rapid expansion of FC applications (Bonomi et al., 2012). Most internet of things devices and applications have some drawbacks in common such as limited computing

capacity and battery consumption capacity of the external mobile terminals (Yu et al., 2019). Different FC features and applications target to improve the performance and engagement of these applications and interchange of information at reduced time and resource requirements. In this way, effective management and support delivery for the FC features and processes can be possible (Zhang et al., 2017). The context of increased demand and processes for the quality of user satisfaction and experience are also related with the deployment of proper FC processes (Liu et al., 2019). In recent time, the applications and utilization of FC has increased the deployment of smart cities, as a result, wireless and wired networks system and applications are increasing (Sun et al., 2017). More and more fog based operations and strategic implications are being implemented to accelerate effective utilization of the postposed scenarios (Luo et al., 2015). Based on the theoretical analysis of the fog computing modelling, this review will analyse different papers relating to the applications of FC. Based on the system theory of fog computing, assessment of the fog computing scenario will be provided (Luan et al., 2015). Contributing to the development of network based support and management opportunity, suggestive approach can be determined.

3.1. Definition of Research Questions

The primary goal of this review is to analyse research works dealing with the resource allocation in different applications of fog computing. To achieve the goal of this research, several research questions have been proposed. Table 1 shows the research questions defined for this research work.

TABLE 1: RESEARCH QUESTIONS

RQ	Contexts
RQ. 1	Why resource allocation in FC is important?
RQ. 2	In fog computing, what are the goals and orientation of resource allocation?
RQ. 3	What are the most used and considered determiners for resource allocation in FC?

RQ. 1 will provide basic overview of the goals of FC resource allocation. With advanced understanding of fog computing, RQ. 2 will provide the basics for resource allocation. Finally, the last question will analyse the most considered metrics and provisions used in different applications of fog computing.

4. Methodology and Search Criteria

4.1. Search Strategy

To attain required results and complying with the research question requirements, a set of keywords had been chosen. Papers have been retrieved from a number of publication databases such as ACM, Elsevier, IEEE, Springer and some other reputed publishers. Basic keywords for the search process was resource allocation and Fog computing. However, in the search process, a number of variations had been selected including AND, OR etc. Subjective analysis was conducted initially to determine if the outcomes of the search items was suitable for the present research question. Exclusion of the papers was conducted in valid and reliable methods. Further inclusion criteria for the search process is listed below.

Table 2: SEARCH INCLUSION CRITERIA

NO	Inclusion Criteria
01	The publishing date of the paper should be recent. Preferably between 2017 and 2020
02	The articles need to be published in different scientific conference proceedings and journals.
03	The papers need to include specific aspects of resource allocation in FC.
04	The writing language needs to be English.

Papers not meeting these criteria are excluded. Only 25 papers have been selected complying with these criteria.

4.2. Keyword Management

The paper targets to analyse the implications for resource allocation in different applications and scenarios of Fog computing. For the selection of the paper, the keyword selection process and combination of resource allocation is relevant to the exploration of the sectors of FC in real world applications. Considering specific restraints and constraints, selection of the devices and management of the low latency applications are implemented within the prospects of internet of things. From the edge computing resource management process, taxonomy related assessment has been conducted by Tocze et al. (Toczé & Nadjm-Tehrani, 2018). Inspired from several keywords such as Resource Allocation, Resource Placement, Scheduling, Workload Distribution and Resource Offloading have been used in this paper.

5. Comparison and Discussion

5.1. Comparative Assessment

Several selected studies have been presented for comparative assessment for the achievement of the research objectives.

Table 3: AUTHOR BASED COMPARATIVE ASSESSMENT

NO	Authors	Comparison
1	(Aazam et al., 2018)	Dynamic resource allocation with reliability based modelling has been depicted in this article. Estimation method targeted to improve the possibility to analyse the implications for fog computing in real world comparison. This dynamic assessment enabled the researcher to demonstrate specific aspects for utilization of the possibility for FC implementation. Dynamic analysis of reliability based modelling.
2	(Dharaskar & Tripathi, 2017)	In this journal, overall basic review of FC have been analysed in order to develop certain criteria for the assessment of the applications. Implications for IoT applications and IoV processes are supportive by this analysis. Basic terminologies for fog computing have been adapted with different aspects of IoT scenarios. Basic demonstration of Terminologies.
3	(Mseddi et al., 2019)	This journal explored fog computing as emerging paradigm to be implemented within wider aspects of IoT applications. Analysing basic resource allocation problems, this article targeted to propose a sustainable proposition for overcoming different issues arising within the scenario of the dynamic assessment of Fog Computing. In order to maintain and attain the research questions, various models and computer based system nodes had been determined by the authors. System model for Fog Computing.
4	(Lahmar & Boukadi, 2020)	This study is a review on the knowledge based analysis of the application of different fog computing setting. This study contributed to the development of necessary applications and management processes for the required network mode, communication model and computation model for fog computing environment.

5.2. Research Question Analysis

In this section, findings from the selected studies will be matched for the research question.

- RQ. 1: Why resource allocation in FC is important? Fog computing has influenced the development of different cloud based operations and functional capability to address the present day needs (Xu et al., 2017). Considering the growth and requirements of different assessment criteria, analysing the required strategic concerns for the fog computing scenarios are important to assess.
- RQ. 2: In fog computing, what are the goals and orientation of resource allocation? In modern day telecommunications and technological advancements, appropriate selection of the resource management processes is necessary. Selected studies primarily targeted to develop relationships for fog only, fog – fog computing arrangement, and fog – cloud relationships are targeted.

Table 4: BASED ON THE TARGETS, PAPER DISTRIBUTION

Contexts	Targets
Fog Computing	(Luong et al., 2017) (Ni et al., 2017) (Nguyen & Pham, 2018)
Fog – Cloud Computing	(Madni et al., 2017) (Amalarethinam & Kavitha, 2017) (H. Zhang et al., 2017)
Fog – Fog Computing	(Islam et al., 2016) (Dai et al., 2015) (Wang et al., 2016)

- Fog Computing

Different research papers have argued different solutions and suggestions to overcome the issues relating to the application of fog computing. Ni et al. proposed the concept of PTPNs which stands for Priced Timed Nets Petri for fog computing implementation (Ni et al., 2017). In this assessment, the researcher argued that pre allocated resources can be determined for improved assessment of the contexts. First Fit Placement theory to determine the resource requirements for different fog computing scenario has been proposed (Nguyen & Pham, 2018). In order to determine the implications for different aspects for the resource distribution can be determined by the researchers to understand the implications for different aspects of resource distribution. In order to find appropriate metrics for resource distribution suggestive aspect for FC technologies can be determined. Quang et al. argued that the First Fit algorithm can be used to determine the aspects for computer controlled environment in which low latency applications are required (Nguyen & Pham, 2018). The algorithm has been designed to specifically determine the outcomes for different aspects for CPU load management, considering the vital aspects for resource distribution and management, bandwidth capacity for different cloud controlled processes. Nguyen et al. argued that organizing specific aspects for determining the vital components for resource distribution and resource allocation can be determined.

- Fog – Cloud Computing

This is complicated for the researchers to implement different scenarios applicable for fog – cloud settings (Zhao et al., 2017). Implementation of fog cloud setting paradigm requires efficient management of latency management (Amalarethinam & Kavitha, 2017). For instance, Nan *et al.* provided effective solution for minimizing the delay in the resource management in fog cloud environment (Ni et al., 2017). Considering the growth challenges and management of the resource, Lyapunov algorithm has been presented in the scenario (Zhang et al., 2017). Elemental change and processing of the performance management aspects for the fog cloud assessment need to be maintained.

- Fog – Fog Computing

Different forms of fog devices and technologies are dependent on specific aspects of resource distribution and management of the considerations for specific aspects for fog computing implementations (Islam et al., 2016). Resource distribution for different fog –fog computing setting remains a vital requirement for enabling the process to continue the performance (Dai et al., 2015). Contributing to the challenging roles for meeting the requirements for assessment of the outcomes for different fog to fog applications can be determined effectively (Wang et al., 2016). Considering the elemental challenge and implementation of the fog – fog computational model, computer based algorithms and support management have been in practice (Meidan et al., 2017). Considering the challenges and management prospects for the fog – fog computing, computer based surveillance has been proposed.

- RQ. 3: What are the most used and considered determiners for resource allocation in FC? In order to assess the final research question, independent research has been carried out based on the combination of the selected keywords. Based on the assessment, necessary changes and modifications in the search criteria have been

considered. From the selected journals, some important metrics such as network delay, latency, resource consumption, resource availability, energy consumption, bandwidth allocation, execution time etc. have been primarily selected. In order to demonstrate effective management of the metrics and determiners for the fog computing implementation, the metrics have been selected carefully to reflect the research understandings.

Table 5: based on the paper distribution

Metrics/ Determiners	Target Studies
Network Delay	(Luo et al., 2015) (Zhao et al., 2017) (Mostafa et al., 2015)
Latency	(Chiang & Zhang, 2016) (Ramadhan et al., 2018) (Shih et al., 2016)
Energy Consumption	(Mostafa et al., 2015) (Chen et al., 2015) (Shih et al., 2016) (Luan et al., 2015)
Resource Consumption	(Zhang et al., 2017) (Ma et al., 2019) (Luan et al., 2015) (Wang et al., 2017)
Resource Availability	(Luo et al., 2015) (Xu et al., 2017) (Modesto & Boukerche, 2018)
Execution Time	(Luan et al., 2015) (M. Wang et al., 2017)
Bandwidth Allocation	(Liu et al., 2017) (Madni et al., 2017) (Mseddi et al., 2019) (Ramadhan et al., 2018) (Luo et al., 2015) (Xu et al., 2017) (Wang et al., 2017)

Several other minor metrics and determiners have been omitted for simplifying the observation. From the evaluation, different metrics and important determiners of the cloud fog, fog computing and fog to fog relationships have been explored. Further research still required to unfold the implications for present day fog computing scenarios.

6. Conclusion

Summarization of the lesson learnt from the literature review and assessment reveals, fog computing and distribution of resources are considered as complex process. Mseddi *et al.* 2020 argued that following system model for fog computing lessens the issues relating to the implementation of fog computing scenarios to a greater extent. However, assessment of the keyword distribution and relation between the implementation processes still remain a challenge for the present work. The analysis reveals that issues relating to the research work are management of the aspects of resource placement, offloading, discarding the selection process and scheduling of the available resources for different FC processes. Modern day communication and acceleration within the aspects of telecommunication have ensured necessary support management for the application for assessment for FC technologies. Optimal allocation for resource management for fog computing needs to be assessed for future improvements. Based on this review, future research opportunities include, minimization of the system delay, improving the fog – cloud performance, improved engagement opportunities for the implementation of the fog computing setting, working on the network delay etc. With the advent of the technological excellence, fog computing will change the future IoT applications and human interaction with technology.

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