Fog Computing-Based Model for Mitigation of Traffic Congestion

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Abstract **- Fog computing enables processing at the edge, while still offering the possibility to interact with the cloud. The massive amounts of data produced from connected applications, as well as the latency-critical issue have motivated researchers to adopt fog computing technology. Development of an effective and reliable traffic system has always been a worldwide concern especially in cities characterized by heavy traffic and high traffic congestion index. Fog computing can help in road traffic congestion mitigation. This paper introduces fog computing and its relevance to both cloud computing and the internet of things (IoT) along with a model for mitigation of traffic congestion. Fog nodes are proposed to be assigned tasks of acquiring, analyzing, and processing local traffic data at traffic junctions. The obtained results show that more reliable traffic is achieved, where congestion could be reduced through homogeneous traffic distribution by regarding the average rate of traffic flow among the fog nodes.**

Keywords - traffic sensing systems; geofence; fog computing; traffic congestion; traffic index; cloud computing

I. INTRODUCTION

In the Internet of Things (IoT), variety of big data will be generated, which is expected to reach 40 trillion gigabytes in 2020, as per the International Data Corporation (IDC) reports [1]. Considering this huge increase in the digital data, Cisco reported that today's cloud models are not designed for the volume, variety, and velocity of data that the IoT generates [2].

In many IoT applications, analysis must be very rapid, and some response or preventive action has to be taken almost immediately, where in the time it takes the data to travel from the device to the cloud for analysis, the chance to prevent a possible damage might be lost. Cisco has reported about such an inevitable emerging challenging task for the IoT systems, and points out that a new computing model, must be developed to handle the volume, variety, and velocity of IoT data [3]. The new emerging model is the fog computing, which is mainly characterized by: minimizing latency, conserving network bandwidth, addressing security concerns, enhancing reliability, securing data collection across a wide geographic area with different environmental conditions, and moving data to the best place for processing.

Fig. 1 illustrates a fog computing architecture for IoT. In this figure, fog computing is operating at the network edge, to bring computation and networking closer to users and data sources. This will reduce latency and increase computational and communication efficiency. In fact, the fog extends the cloud to be closer to the things that produce and act on IoT data.

In Figure. 1, the devices, called fog nodes, can be deployed anywhere with a network connection. They can be on a factory floor, in a road intersection, alongside a railway trail, in a motor vehicle, or in a greenhouse. Any device being characterized by computing, storage, and network connectivity can be a fog node.

In section 2 of this paper, a reference is made to the architecture, guides, and use cases given by OpenFog Consortium to help in understanding the true value of fog computing. The traffic congestion problem, and its negative consequences is mentioned in section 3, along with the forecast of adopting fog computing technology for possible mitigation. Section 4 refers to the scope and published work in the field of traffic control and management systems. The proposed traffic congestion mitigation model is presented in section 5, while some concluding remarks about the paper are mentioned in section 6.

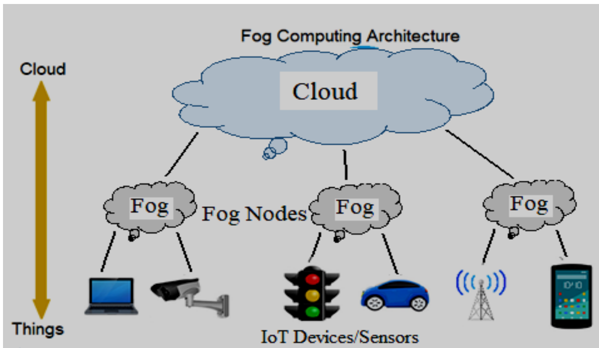

Figure. 1. A Fog Computing Architecture for IoT

II. Fog Computing-Based Applications

Fog computing has its own international supporting association named the OpenFog consortium founded in 2015. This association comprises of high tech industry companies and academic institutions across the world aimed at the standardization and promotion of fog computing in various capacities and fields [4]. The consortium offers guides, use cases, market analysis and plans that help developers and IT teams understand the true value of fog computing. In February 2017, OpenFog Consortium published the OpenFog Reference Architecture for fog computing. This document presents and discusses eight technical pillars for fog computing (namely; Security, Scalability, Open, Autonomy, Programmability, RAS (Reliability, Availability, and Serviceability), Agility; and Hierarchy) [5].

Considering the integration of cloud and fog computing, the breakdown of what assignments and tasks go to fog and what goes to the cloud are application specific. This breakdown could be allocated based on a certain plan that may itself change dynamically if the network state changes.

According to the OpenFog architecture, applications characterized by issues of, security, cognition, agility, latency, and efficiency are advised to be assigned to the fog nodes [6]. Applications in the fields of transportation, agriculture, healthcare, hospitality, smart-cities, smart–buildings, financial services, that are network-constrained and mostly require real-time decision making, low latency, improved security, are examples of fog nodes tasks in IoT applications.

In our paper, a transportation related case is adopted, and the proposed model for traffic control and congestion mitigation is analyzed to demonstrate traffic flow optimization through simultainous actions of fog nodes.

III. Fog Computing-Based Traffic Control Systems

Traffic congestion is a growing severe problem, that has the possibility to paralyze major cities, slowing down growth and prosperity. Some cities are considering measures, like expanding toll roads or restricting the number of licensed vehicles. Such measures can be both expensive and of harsh effect on travelers.

Traffic index, which is defined as the relation between the busiest traffic times (rush hours) compared to free flow traffic situations, is up by 23% globally since 2008 with some noticeable differences between continents. Traffic index is an indicator of traffic congestion. Between 2015 and 2016, for example, North America’s traffic congestion has increased by 5%, while Asia and Oceania are both up by 12%, and Africa, by 15% [7].

World cities featured by heavy traffic and high traffic index, however, are now equipped with a promising solution of targeting congestions through implementation of traffic control system based on the open architecture of fog computing [8].

Fog computing has the flexibility to control big data, which enables cities to take measures to lessen congestion by forming an infrastructure to which traffic-related devices, roadside sensors, and on-board vehicles can be connected in order to manage traffic based on real-time data.

The work in this paper is motivated by the case of a city called Salalah located in Oman, which is populated with just less than 200 thousand. During two months of each year (namely July and August), this city becomes a tourist attraction. Number of tourists may vary from time to time, however, statistics reports that the number of tourist during the first week of August 2016 has reached 472.2 thousand. This added number to the original population makes the traffic index exceede 100% [9].

IV. Related Works

It has been always an urgent need to keep improving traffic control and management. Many microcontroller-based smart and intelligent systems utilizing GPS are proposed in literature [10], [11]. Intelligent traffic control system using PLC can be also found in [12] and [13]. Wireless technology is used in the development of traffic control systems, where in [14] a prototype using a microcontroller and XBEE interconnected with multiple wireless sensors is developed.

With the appearance of cloud computing followed by the Internet of Things (IoT), and recently the fog computing, new trends for intelligent traffic systems were proposed and/or developed. In [15], a study about the feasibility of implementing urban traffic control systems ‘on the cloud’ is presented. Brizgalov et al in [16], proposed an architecture of the traffic control systems using cloud computing. In [17], Perumalla et al., presented a prototype architecture, that is developed using a microcontroller board, an IoT board, and a GPS module. In [18], Rizwan et al., proposed a system in which the Internet of Things (IoT) is used for traffic data acquisition and processing.

The advent of fog computing and its involvement in many practical applications is growing very fast, and the fog computing market is expected to grow from $22.28 Million in 2017 to reach $203.48 Million by 2022 [19]. Number of works based on fog computing that are serving the field of smart transportation in general, and traffic monitoring and control, in particular are published in literature. Liu, et al., in [20], proposed schemes for smart traffic light control using fog computing. In the OpenFog reference architecture document, a smart vehicle and traffic control use case is included [5]. In this use case, mobile fog nodes are used to support Vehicle-to-Vehicle (*V2V*), Vehicle-to-Infrastructure (*V2I*), and Vehicle-to-X (*V2X*) interactions. Both private and public fog and cloud networks are used by this smart vehicle and traffic control proposed framework.

V. THE PROPOSED MODEL

A. Fog nodes assignments

Traffic congestion in the city of Salalah, during the tourist season, is mostly occurring in the city center, therefore our model will focus on this region. The main traffic junctions of the city center are shown in Fig. 2., which is a map extracted from the OpenStreetMap [21]. In Fig.2., the notation *FN1* to *FN16* represent the proposed fog nodes, that will be assigned traffic managements tasks within their local sectors. These nodes will be distributed within an area of about 4.5 Km^2 counted based on the distances between the boundary fog nodes (*FN1, FN5, FN14*, and *FN16*). The distance between *FN1* and *FN5* is 2.26 Km and the maximum allowable speed is 80 Km/hr, while the distance between *FN5* and *FN16* is 1.56 Km and the maximum speed is 60 Km/hr. Between *FN16* and *FN14*, the distance is 2.46 Km and the maximum speed is 60 Km/hr, and finally, the distance between *FN14* and *FN1* is 2.22 Km and the maximum allowable speed is 100 Km/hr.

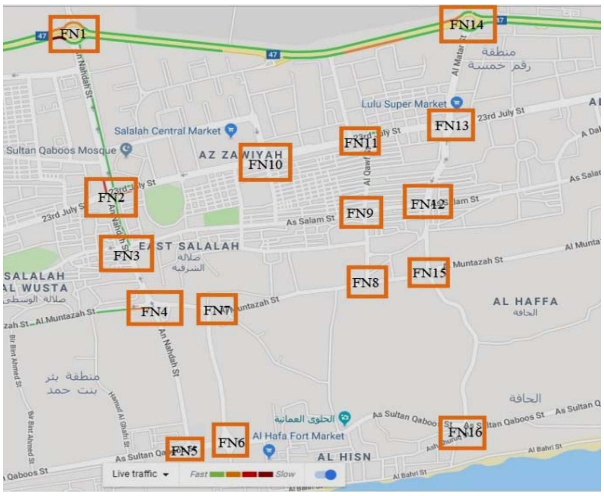

Figure.2. City center map showing proposed fog nodes sectors

Junctions, where the fog nodes are assigned, are different in their types. Some of them are roundabouts, while others are traffic circles, three or four-way intersections, or a box junction. For the purpose of illustration, we consider the fog node *FN1*, which is related to a four-way intersection, as shown in Fig. 3. The traffic of this intersection is assumed to be monitored, controlled, and the relevant data is analyzed and processed in this fog node. For traffic to be monitored in a specific geographical region, the model assumes that geofence technology can be adopted to define virtual boundaries, where vehicles can be detected and counted within the assigned geofence area. The geofence is a virtual polygon representing geographic boundary, defined by GPS or RFID technology, that enables software to report a response when a mobile device enters or leaves a particular area [22]. The fog node *FN1* will be considered as a rectangular polygon geofence, that is defined by only four pairs of coordinates. Since it is possible to assign a geofence that has some overlap with another geofence, each side of the intersection related to *FN1* is further divided up into two rectangular geofences denoted as *A* to *H*. The geofences A, *D, F,* and G represent the traffic accumulation areas. Vehicles entering a geofence are assumed to be detected, where the location of the vehicle is determined and can be added to a count to evaluate traffic volume.

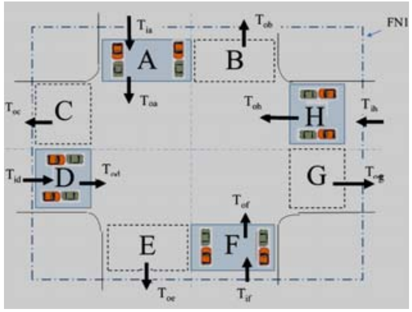

Figure 3. A road intersection, typical fog node architecture

In Fig. 3, it is assumed that counts of input and output traffic can be monitored by the implementation of geofences.

B. Modelling of the Boundary Fog Nodes

With reference to Fig.2, the total traffic within the area of the city center is assumed to be bound within the corner fog nodes (*FN1, FN5, FN14*, and FN*16*). The normal traffic flow through these nodes is the contribution of traffic flowing in all possible directions that is forming what can be considered as an open loop traffic flow, as shown in Fig. 4.

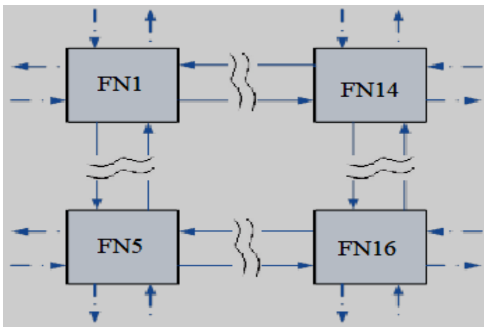

Figure 4. Open loop fog nodes

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By ignoring some traffic entry to the boundary nodes, and restricting the traffic to only entry/input and exit/output points to each fog node, a closed loop model is achieved, as shown in Fig. 5.

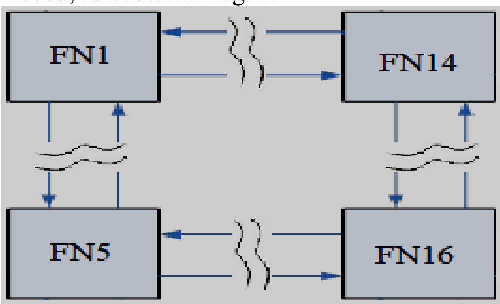

Figure 5. Closed loop fog nodes

C. *Waiting Times Calculation and Adjustment*

Waiting times of traffic is varied in such a way as to avoid congestion by equal distribution within the closed loop. A hypothetical closed loop model composed of four interacting fog nodes is considered, as shown in Fig. 6. Two waiting times at each fog node need to be calculated, and they are the ones related to the position of the fog node in the closed loop. At *FN1*, waiting times for east-bound and south-bound traffic are denoted by *FN1_Te* and *FN1_Ts* respectively.

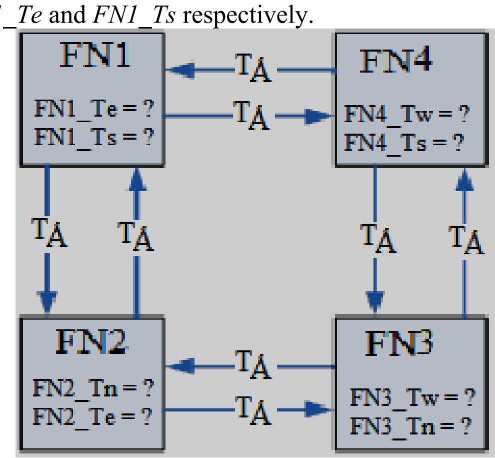

Figure 6. Waiting times for corner fog nodes in the closed loop

Change in waiting time affects the traffic count of fog nodes. This waiting time is dependent on the traffic distribution factor (*k*). Equal distribution of traffic in each fog node is desired. Additional traffic is either moved to or out of transition area (*TA*). Distribution factor is calculated as the function of node's capacity and the count of vehicles per unit of node's capacity.

Loop with distribution factor (*k*) is required to reach traffic distribution target with each adjusted value (*k1, k2, k3, k4*) for nodes is updated and the waiting time of traffic at each node is executed until next adjustment is required.

Loop
{
k1 (FN1_Te) → k2(FN2_Tn) → k3(FN3_Tw) → k4(FN4_Ts)
k1 (FN1_Ts) → k2(FN2_Te) → k(FN3_Tn) → k4(FN4_Tw)
(1)
}

D. *Labeling and Convention*

Referring to Fig. 6., which is showing the main traffic flow in the proposed closed loop model, further details and assumptions are considered. It is assumed that main roads are connecting the fog nodes with traffic following four lanes in each main road. Two traffic lanes for traffic input and two for traffic output. For each traffic direction in the main road, there is a traffic light signal, where the traffic is moving in anticlockwise direction, as shown in Fig. 7. In order to count traffic, the model is divided up into segments based on the expected flow.

A scheme is followed for labeling the road segments, as shown in Tables I and II. A straight segment exiting from *FN1* and entering *FN2* is labeled as *S12*. Curved segments making the U-turn are labeled using conventional exiting and re-entering scheme. For-example, *S11*, is a U-turn exiting from *FN1* and entering the other direction of FN1.

Other curved segments are pairs of each *S13, S31, S42* and *S24*. In order to find where each of the segment pairs belongs, a preceding and succeeding segments are to be tracked. For-example, traffic originating from *S34* using *S31* and moving towards *S41* will be identified as west-bound traffic using bypass at *FN4*.

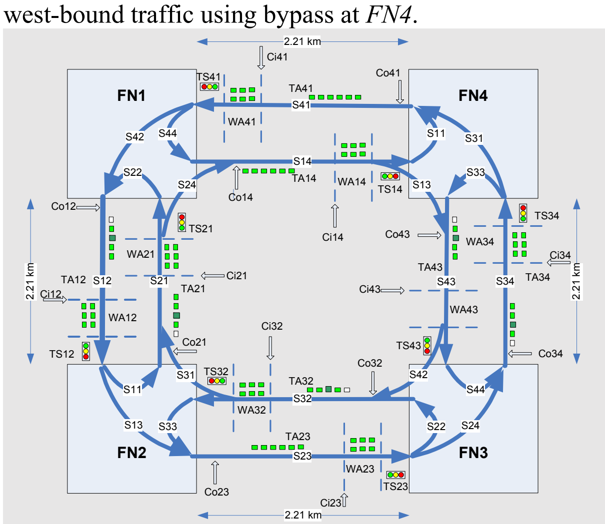

Figure 7. Identification of Main Road (*S*), Bypasses (*S*), Transition Areas (*TA*), Waiting Areas (*WA*), Counters (*C*), and Traffic Signals (*TS*).

TABLE I. SEGMENT, BYPASSES IDENTIFICATION SYSTEM

S. No.	Type	Segment	Area	Pre-decease	Such-censor
1	Bypass	S42	FN1	S41	S12
2	Bypass	S24	FN1	S21	S14
3	Bypass	S31	FN2	S32	S21
4	Bypass	S13	FN2	S12	S23
5	Bypass	S42	FN3	S43	S32
6	Bypass	S24	FN3	S23	S24
7	Bypass	S31	FN4	S34	S41
8	Bypass	S13	FN4	S14	S43
9	Segment	S11	FN2	S12	S21
10	Segment	S22	FN1	S21	S12
11	Segment	S33	FN2	S32	S23
12	Segment	S44	FN1	S41	S14
13	Segment	S11	FN4	S14	S41
14	Segment	S22	FN3	S23	S32
15	Segment	S33	FN4	S34	S43
16	Segment	S44	FN3	S43	S34

TABLE II. MAIN ROAD SEGMENTATION AND IDENTIFICATION

S. No.	Type	Segment	Area
1	Main road	S12	TA12
2	Main road	S23	TA23
3	Main road	S34	TA34
4	Main road	S41	TA41
5	Main road	S14	TA14
6	Main road	S43	TA43
7	Main road	S32	TA32
8	Main road	S21	TA21

Adjacent to each fog node, there are four geofence-based traffic counters. The counters are installed in such a way that they count the traffic entering or exiting each direction of the main road. Traffic deviation from a lane to bypass or segment is random based on the decision of the drivers after waiting at the traffic light.

Referring to Fig. 7, other parameters participating in the model dynamic evaluation are; the Waiting Areas (*WA*), Transition Areas (*TA*), and Traffic Signals (*TS*). These parameters are denoted as follows:

Waiting Areas (WA): WA12, *WA21*, *WA14*, *WA41*, *WA23*, *WA32*, *WA34* and *WA43* each with a maximum capacity determined using a group of vehicles composed of the light, medium and heavy vehicles.
Transition Areas (TA): TA12, *TA21*, *TA14*, *TA41*, *TA23*, *TA32*, *TA34* and *TA43* with average and maximum capacity for each vehicle of type light, medium, heavy.
Traffic Signals (TS): TS12, *TS21*, *TS14*, *TS41*, *TS23*, *TS32*, *TS34* and *TS43*.

E. Model Evaluation

Evaluation of the dynamic behavior of our distribution algorithm requires, for each fog node, the following calculation:

a. Rate of accumulation of traffic in each *WA*.
b. Rate of discharge of traffic from each *WA*.

To work towards our objective of finding the optimized waiting time (Wt) of each traffic signals, we look at each fog node individually. For example, consider FN1, the following are some assumptions about waiting time for traffic in the waiting area WA41:

i. Ignoring the bypass traffic and assuming that the traffic of the main road along the outer loop is controlled by varying the timing of the traffic signals *TS41, TS12, TS23*, and *TS34*.
ii. The traffic of main road along the inner loop is controlled by varying the timing of the traffic signals *TS14, TS43, TS32*, and *TS21*.
iii. For traffic of fog node FN1, there is an associated waiting area (*WA41*) with density *dWA41*.
iv. The density of predecessor transition area (*TA41*) is *dTA41* and density of the successor transition area (*TA12*) is *dTA12*.
v. Transition area, which is a predecessor to a given fog node FNx, is denoted by *TAp* and that of successor is denoted by *TAs*.

Assuming the system is a closed loop with no entry or exit of traffic to the loop, the model is simulated for 91 vehicles (small green boxes) of light (89%), medium (5.5%) and heavy (5.5%) vehicle types. Ideally equilibrium is achieved with equal distribution of traffic i.e. 6 of the light vehicles at each of the identified Areas (*WAs* and *TAs*) whereas in some areas there are 4 light, 1 heavy and 2 medium vehicles.

The optimal waiting time of each traffic signal can be manipulated relative to other traffic signal timings. To control the even distribution of traffic around each loop we distribute the time among the following variables holding the delay time for traffic signals:

(waiting times for the outer loop's traffic)
Wt_TS41, Wt_TS12, Wt_TS23 and *Wt_TS34* (2)

(waiting times for the inner loop's traffic)
Wt_TS14, Wt_TS43, Wt_TS32 and Wt_TS21 (3)

Under normal driving conditions, we can predict traffic behavior, e.g. the average time to reach full capacity at waiting area (*WA*) since the opening of the predecessor traffic signal, or the time to discharge traffic from the waiting area (*WA*) after the opening of the TS associated with the *WA*. The average time will stay within the predicted limits as long as the loop dimensions and road conditions remain constant.

tC: Time elapsed, measured now, to reach full capacity of *WA* (maximum count of triggers at *WA*) since the last opening time of traffic signal of the predecessor *WA*.

tP: Time elapsed, measured previously, to reach full capacity of *WA* (maximum count of triggers at *WA*) since the last opening time of traffic signal of the predecessor *WA*.

Subtracting tC from tP will result in either of the following conditions based on which we can estimate the situation of the focused node and the desired action:

TABLE III. CONDITIONS EMERGING AT WAITING AREAS BY CALCULATING THE AVERAGE TIME

Condition	**Situation at current fog node**	**Desired action**
If (tC – tP) > 1 i.e. tP < tC	Congestion rate down	Increase the wait time of the predecessor *TS* by 1,
If (tC-tP) < 1 i.e. tP > tC	Congestion rate up	Decrease the wait time of the predecessor *TS* by 1.
If (tC-tP) = 0 i.e. tP ≈ tC	Same traffic flow rate	Keep the same wait time of the predecessor *TS*.

While looking at Table III, we can observe that if the current time (*tC*) to reach full capacity of *WA* at the current fog node is equal to the previous time to reach full capacity at WA then we can conclude that the traffic flow in the predecessor *TA* is not changing rapidly. This hols true to calculating for all the fog nodes.

The terms *tP* and *tC*, are defined as the sum of elapsed time intervals in milliseconds (of each trigger) since the traffic light at the predecessor node was last turned green, averaged over the count of triggers.

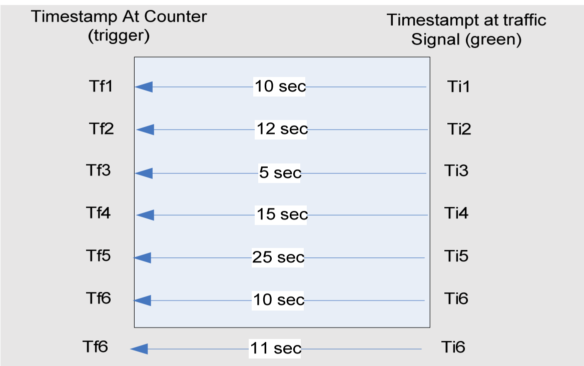

Figure 8. Time elapsed between signal turning green and counter trigger

$$t = \frac{Sum\ of\ All\ elapsed\ time\ intervals}{number\ of\ trigger\ counts} \quad (4)$$

In Fig. 8, each arrow represents a vehicle (e.g. it took 10 seconds by two vehicles to reach from signal to the counter). we took only one-time interval as timestamp *Tf1* minus the *Ti1*. To complete the samples for calculating the average time we took the next unique interval (11 seconds).

$$tC = \frac{10+12+5+15+25+11}{6} = 12.83\ Seconds$$

$$tP = \frac{25+35+27+23+26+29}{6} = 27.5\ Seconds$$

In the above result, current reading (tC) and the previous reading (tP) is less than 1 (i.e. -14.67), and hence the congestion rate is up, therefore action would be to increment the TS at the predecessor.

$$If\ (\sum(Ci41 > 0)\ \&\ \sum(Ci41 <= dWA41)\ \text{and}\ (\sum(Ci41 < 0)\ \&\ \sum(Ci41 >= dWA41) \quad (5)$$

VI. CONCLUSION

Fog Computing is based on a platform that provides services between end devices and data centers located at the edge of network. The model proposed in this paper exhibits a clear fulfillment of the main fog computing characteristics. Services are supported at the edge of the network to ensure low latency. The application offers highly distributed network and services supported by the utilization of location identity with a provision to mobility. Speedy services are attainable through real-time interconnections. Heterogeneity is also supported, where fog nodes are deployed in wide variety of environments.

Cloud computing, that has a great impact on both individuals and businesses, comes with several inherent capabilities, and it is widely used nowadays. It is, however, still having some constraints, including its limitation for the connectivity between the cloud and the end devices. To tackle challenges facing the cloud computing, a new emerging technology, which is fog computing, is introduced. In fog computing applications, the data collected are not sent to cloud server but to nearby devices for processing thus improving the quality of service and also reducing latency. In this paper, a transportation related case pertaining to the city of Salalah in Oman is adopted, where a model for traffic control and congestion mitigation is developed and presented. Dynamic scenario of traffic model is considered with the proposed case study. Traffic conditions are logically analyzed and traffic flow is optimized through simultaneous actions at multiple fog nodes. Results show that traffic congestion could be reduced through intervention leading to homogenous traffic distribution for congestion mitigation.

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