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SUSTAINABLE CLOUD COMPUTING FOR COGNITIVE INTENT BASED NETWORKS

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ABSTRACT

Intent based networks enable auto-configuration and require low latency access to cloud platforms. The use of cloud platforms incurs high operational costs. Low latency access can be realized by siting data centres close to subscribers. This paper proposes aquaria data centers with low operating costs and latency. In LTE, cloud platforms are normally accessed via the packet network gateway reachable via the serving gateway and mobility management entity. Aquaria data centers are sited close to LTE subscribers and accessed via the mobility management entity. This reduces the size of control packets in the LTE network. Simulations show that the proposed architecture reduces the size of control packets by up to 49.7% and 99.3% when header packets are uncompressed and compressed respectively. The delay associated with receiving configuration information is reduced by 50% on average. The channel capacity is enhanced by up to 22.8% on average.

Keywords: *Data centers, LTE-Advanced, Peak Age of Information, Channel Capacity, Header (Control) Packets*

1. INTRODUCTION

Cloud platforms comprising data centres have high operational costs and play an important role in data processing in intent based networks. The use of significant amount of water in data centres necessitates the need to design mechanisms reducing data centre water usage. This has led to the consideration of water use efficiency in sustainable data centre design [1 - 4]. There is also increasing concern on ensuring data centre sustainable operation. This has led to the use of renewable energy in data centres [5-6]. The cooling costs can be reduced by changing data centre location to alternative locations such as the ocean [7-9].

The use of underwater data centres is unsuitable for geographical locations with insufficient maritime resources. Nevertheless, such geographical locations should be able to host data centres. This can be realized by hosting data centres in large aquaria. This paper proposes a network architecture that incorporates aquaria data centres (low latency access) in long term evolution (LTE) networks incorporating intent based networking paradigm.

The major contribution of the paper is that the paper proposes an architecture incorporating aquaria data centres that process data in LTE-Advanced (LTE-A) intent based networks. The intent based networks execute intelligent auto-configuration [10-11]. They require access to computational resources in aquaria data centres for big data processing and learning. Aquaria data centres should be accessible by subscribers (far from significant maritime resources) at low latency. In LTE-A, this is achieved by accessing data centres via the mobility management entity instead of via the packet data network gateway. The aquaria data centres incorporate low

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power neuromorphic computing processors [12-13]. The paper formulates the quality of service (QoS) metrics of size of control packets, latency and channel capacity to examine the performance benefits of the proposed architecture.

The rest of the work is organized in the following manner. Section II discusses background work. Section III and Section IV presents the problem under consideration and proposed architecture respectively. Section V formulates the performance model. Section VI focuses on simulation and analysis of performance benefits. Section VII is the conclusion.

2. RELATED AND BACKGROUND WORK

Sharma *et al.* [14] examine the resource usage of the Massachusetts Green High-Performance Computing Center. They recognize that the consideration of the geographical location is beneficial in reducing data centre operating costs and enhancing the power usage effectiveness (PUE). The paper recognizes that lesser attention has been paid to water usage effectiveness in comparison to the PUE. They examine the monthly water usage of the Massachusetts Green High-Performance Computing Center. It is also recognized that there is limited availability of data on water usage effectiveness. Though, [14] presents insights on the use of sustainable technologies in data centers; the focus is on Massachusetts and not other locations.

Wu *et al.* [15] address the challenge of reducing data centre cooling energy by siting data centers in locations with a cold climate. They recognize this as a direction being considered by cloud computing operators. An alternative to this approach is using smart temperature monitoring in future data centers. They present a scheduling architecture that reduces data centre cooling power while considering QoS. The scheduling algorithm distributes workloads across geographically distributed data centres. The distribution of workload reduces the heat generated and the cooling energy across the cloud computing platform. They examine workload distribution across Microsoft data centres located in Chicago, Quincy and San Antonio all in the US. The performance of the proposed mechanism for data centers across different national borders is not considered. However, additional research is required to evaluate if the performance benefit apply to data centers located in regions within different countries.

Gill *et al.* [16] also recognises that cooling consumes a significant amount of power in data centre operation. They consider the recirculation index, water economizer utilization factor and data centre cooling system efficiency as performance metrics. The paper recognizes the suitability of free cooling for reducing cloud data centre cooling costs. In realizing cooling management, it is recognized that site data centers should leverage on free cooling. However, additional research is required to recognize these locations and design mechanisms suitable for leveraging on free cooling.

Li *et al.* [17] propose the use of the reinforcement learning algorithm in optimizing data centre cooling and performance. The artificial intelligence technique enables the determination of the optimal set-points for cooling system control variables. This does not consider using free cooling to reduce cooling costs. Instead, it optimizes cooling system performance. A similar discussion on the role of intelligence is in [18].

The discussion in [14-18] focuses on large cloud platforms. The operational advantages of large scale cloud service providers are inaccessible to cloud service providers with small sized data centers [19]. Such benefits include ease of implementing cooling system economizer and operational consolidation. Large data centers use a smaller energy per processor in comparison to small data centers. Though, [19] points out that large data centers operation is beneficial in comparison to small data centers; the acquisition of large data centres results in high costs. Moreover, [19] assumes that small and large data centers makes use of conventional data centre cooling solutions without consideration for free cooling.

Studies such as that of Stergiou *et al.* [20] consider cloud computing from an application perspective. An application perspective of cloud computing technology considers issues focused on consistent delivery of good quality of service for cloud based applications to different users at reduced support costs. This perspective is found in [21-22].

The scale of data centers should be considered from the perspective of leveraging on free cooling. This should consider the climate of different regions. Hence, data centres utilizing free cooling should be considered for applications requiring computing resources such as intent based networks [10-11, 23-24].

Intent based networks incorporate intelligent capability and generates network configuration strategies from subscriber QoS requirements; and benefit from artificial intelligence and software defined networks. In intent based networks, data describing subscriber requirements are the inputs. Advances in artificial intelligence have led to the emergence of new paradigms such as meta-cognition. However, meta-cognition in [25 -26] has being considered for cognitive radio and not intent based networking.

The realization of the goal of intent based networking requires processing of data describing expectations from subscribers by network providers. This requires having access to computing resources via data centers. This is necessary as intent based networks bring the benefits of cloud computing and artificial intelligence to network infrastructure management [27].

The findings of the discussion are summarized as follows:

1) ***Sustainable Cloud Computing***: There is an increased use of sustainable technologies in cloud computing [14-18] accompanied by consideration of geographically aware free cooling strategies.

2) ***Siting of Data Centres in Alternative Locations***: Initiatives considering the siting of data centers in the ocean to benefit from free cooling cold water are also receiving consideration [7 – 9].

3) ***Use of Artificial Intelligence for Improved Cooling***: The use of artificial intelligence techniques for realizing the optimal configuration of data centre cooling systems has been considered in [17].

4) ***Emergence of Intent Based Networking***: The review recognizes that intent based networks present a new networking paradigm. This paradigm requires having access to data centers with low cooling costs for big data processing, and learning mechanism development.

The incorporation of cloud computing in intent based network should meet the following objectives:

1) ***Low Latency***: Data describing QoS expectations and network configuration should have low latency transmission. Data emerging from intent based networking shouldn't cause congestion.
2) ***Environment Friendly and Sustainable***: The data centers to be used for data processing and learning mechanism related computation should incorporate free cooling mechanisms.

A summary of the research findings is also shown in Table 1.

3. PROBLEM DESCRIPTION

This section presents the problem being addressed. The scenario is one in which subscribers' access applications at desired QoS levels in LTE-A via intent based networking. The LTE-A network has interference-free spectrum access. Cloud platforms execute the big data processing related to intent based networking. The assumption is shown in Table 2.

Table 1: Summary of research findings considering different criteria.

S/N	Reference	Criteria						
		Energy Efficiency	Change of Geographical Location	Water Usage	Artificial Intelligence for enhanced operation	Free Cooling/ Leveraging on cold climate	Renewable Energy	Sustainable Operation
1	Hoekstra *et al.* 2015, [1]	Y	N	Y	N	N	N	Y
2	Ristic *et al.* 2015, [2]	Y	N	Y	N	N	N	Y
3	Islam *et al.* 2016 , [3]	Y	N	Y	N	N	N	Y
4	Reddy *et al.* 2017, [4]	Y	N	Y	N	N	Y	Y
5	Sheme *et al.* 2016, [5]	Y	N	N	N	Y	Y	Y
6	Buiatti *et al.*, 2018, [6]	Y	N	N	N	N	Y	Y

S/N	Reference	Criteria						
		Energy Efficiency	Change of Geographical Location	Water Usage	Artificial Intelligence for enhanced operation	Free Cooling/ Leveraging on cold climate	Renewable Energy	Sustainable Operation
7	Cutler *et al.* 2017, [7]	Y	Y	Y	N	Y	N	Y
8	Krein 2017, [8]	Y	N	N	N	N	N	N
9	Periola, 2018 [9]	N	Y	Y	N	Y	N	Y
10	Sharma *et al.* 2017, [13]	Y	N	Y	N	Y	Y	Y
11	Wu *et al.* , 2018 [14]	Y	N	N	Y	N	N	N
12	Li *et al.* 2019, [17]	Y	N	N	Y	N	N	N
13	Shoukourian *et al.* 2018, [18]	Y	N	N	Y	N	N	N
14	Shehabi *et al.* 2019, [19]	Y	N	N	N	N	Y	Y
15	Christos *et al.* 2018, [20] ; *	N	N	N	N	N	N	N
16	Zhaolong *et al.*, 2018, [21] ; *	N	N	N	N	N	N	Y

* Sustainability considers the perspective of ensuring efficient operation with meeting subscriber QoS requirements. Y – Yes; N – No.

Table 2: Considerations for Networking Scenario

S/N	Consideration	Assumption(s)
1	Subscriber(s)	Subscribers are enterprise subscribers or individual subscribers and can access wireless spectrum without interference.
2	Base Station Entities	Base station have connections to cloud infrastructure i.e. data centers via either wireless or wired connections.
3	Data Centers	Comprise networked servers that are located on ground. In addition, data centers are connected to wireless network entities via gateways and interact with base station entities.
4	Base Station Entities – Data Centers distance	Base station entities interact with subscribers across different geographical locations. They have a variable distance from the base station entities.
5	Bandwidth	Wireless networks have access to bandwidth in the range of tens to hundreds of MHz Achievable bandwidth is also in the range of tens to hundreds of Mbps.
6	Cooling	Data centers utilize conventional cooling mechanisms and solutions that are based on chillers and air-conditioning.
7	Operational Power	Data centers and wireless networks can use either non-renewable or renewable energy.
8	Fog and edge nodes	Fog nodes attached to networks are used for internet of things applications only.

Let α , β and γ denote the set of subscribers, networks and data centres respectively.

$$\alpha = \{\alpha_1, \alpha_2, \ldots, \alpha_I\} \tag{1}$$

$$\beta = \{\beta_1, \beta_2, \ldots, \beta_J\} \tag{2}$$

$$\gamma = \{\gamma_1, \gamma_2, \ldots, \gamma_K\} \tag{3}$$

Where I, J and K are the total number of subscribers, networks and data centres respectively.

The number of gateways between subscriber $\alpha_i, \alpha_i \in \alpha$ and data center $\gamma_k, \gamma_k \in \gamma$ at epoch $t_y, t_y \in t, t = \{t_1, \ldots, t_Y\}$ is denoted $N(\alpha_i, t_y)$. In addition, let $\vartheta(\alpha_i, \gamma_k, t_y)$ denote the latency between subscriber α_i and data center γ_k at epoch t_y. Data describing subscriber QoS expectations are conveyed to the data center via LTE-A base station and required gateway. The data is analysed to derive network configuration strategies and used by software defined network and function virtualization modules. Let $\vartheta(\alpha_i, t_y)$ denote latency associated with transmitting configuration strategy to software defined network controller for subscriber α_i at epoch t_y. Given a threshold latency, $\vartheta_{threshold}$, the i^{th} subscriber α_i experiences a significant delay when:

$$\vartheta(\alpha_i, \gamma_k, t_y) + \vartheta(\alpha_i, t_y) \geq \vartheta_{threshold} \quad for\ each\ subscriber \qquad (4)$$

Considering the case of multiple subscribers collocated with subscriber α_i and under the coverage of a base station entity in the wireless network. A significant delay is associated with accessing data centre γ_k arises when:

$$\frac{1}{I \times Y}\left(\sum_{i=1}^{I}\sum_{y=1}^{Y}\vartheta(\alpha_i, t_y) + \vartheta(\alpha_i, \gamma_k, t_y)\right) \geq \vartheta_{threshold} \qquad (5)$$

Where I and Y are the total number of subscribers and epochs respectively.

The condition in (5) is satisfied when high latency arises in transmitting (i) data on QoS requirements to data center or (ii) transmitting configuration strategies to the software defined network entity.

4. PROPOSED SOLUTION

This section presents the solution and proposes siting data centres close to subscribers to reduce the latency. Such a consideration has been made in the fog or edge computing for internet of things [28-30]. However, the target application here are subscribers in wireless networks incorporating intent based networking.

This section is divided into two parts. The first part discusses sustainable aspects of aquaria data centres. The second focuses on integration of proposed data centres into LTE-A.

4.1 Aquaria Data Centres – Sustainable and Environment Friendly Option

An aquarium is a controlled environment where temperature is kept at a level required for marine species survival. The use of aquarium is proposed for regions with limited maritime resources.

Aquaria temperature is influenced by the water type. Aquaria water type can be either freshwater or seawater [31]. Typical temperatures for freshwater type aquaria are 13.7^{O}C, 17.2^{O}C and 28.3^{O}C [31]. In seawater type aquaria, typical temperatures are 14.8^{O}C , 25.1 ^{O}C, 26.1 ^{O}C, 26.2 ^{O}C and 26.3 ^{O}C. [31]. These values are in the range of the recommended temperatures specified by the American Society of Heating, Refrigerating and Air-conditioning Engineers [32]. Information in [32] shows that the recommended dry bulb temperature for data centres in classes A1, A2, A3, A4, B and C lie in the range 5^{O}C to 45^{O}C. Data in [32] shows that the allowable temperature increase for classes A1, A2, A3 and A4 is 0.25^{O}C. Therefore, using aquarium for data centre hosting and cooling is feasible.

Modern aquaria incorporate smart solutions [33-34] but the use of aquaria has been considered mainly in aquaculture and marine biodiversity [35-37] and not data centre hosting. Aquaria have different sizes and can be small, medium or large. Large aquaria can be used to host a significant number of servers. The servers used in a data centre can be deployed across multiple aquaria and inter-connected via fibre links.

In the proposed solution, cloud service providers using aquaria data centres jointly pay municipal water authorities for providing water for server cooling. Alternatively, cloud service providers can pay operators and organizations owning large sized aquaria a data centre hosting fee. The aquaria data centre uses renewable solar energy and freshwater from rivers. Siting the proposed data centre near large rivers makes it easy to obtain water for aquaria operation. Furthermore, the aquaria data centre utilizes solar energy.

4.2 Aquaria Based Data Centres – Role in Wireless Networks

Aquaria data centres host computing payload used in intent based networks to translate information describing subscriber QoS requirements into network configuration strategies. The wireless network standard that incorporates intent based networking in LTE–A. Cloud platform access in LTE-A prior to incorporating aquaria data centre is shown in Figure 1. In Figure 1, subscribers under the coverage of an evolved Node B (eNB) transmit and receive data from other subscribers. The eNB is connected to the mobile management entity (MME) which executes inter-eNB handover. The MME is connected to the serving gateway (S-GW) which is linked to the packet data network-gateway (PDN-GW) enabling access to the cloud platform. The S-GW, PDN-GW and the accessed cloud platforms are at different locations and far from each other. The large distance between the PDN-GW and subscribers implies that the transfer of big data to the cloud platform for translation intended in intent based network results in large latency thereby degrading subscriber QoS. The aquaria data centres are accessible via the MME through the eNB. This reduces the latency because there is no need to access the cloud platform through the S-GW and PDN-GW. The network scenario after the incorporating the proposed architecture is in Figure 2. The scenario in Figure 2 shows the case where there are four aquaria data centres. The aquaria data centres AqDC 1, AqDC 2, AqDC 3 and AqDC 4 are accessed via the MME and not the S-GW or PDN-GW.

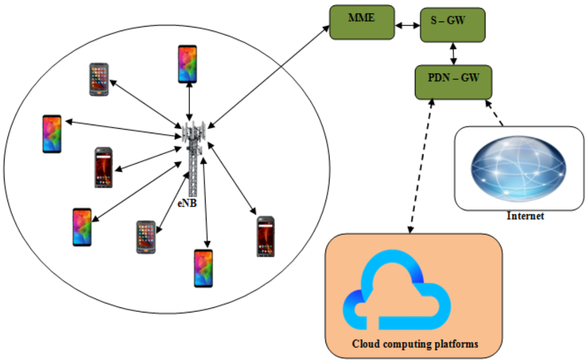

Figure 1: Cloud access in LTE-A in the absence of the proposed mechanism.

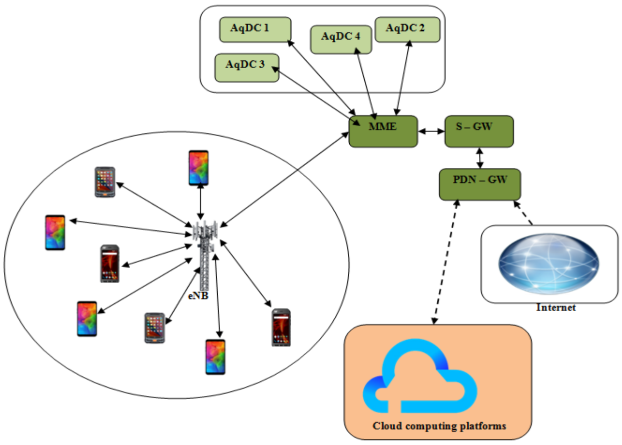

Figure 2: Cloud access in LTE-A incorporating the aquaria data centre.

The aquaria data centres host the software defined network and network function virtualization entities and modules. The MME executes the tasks of assigning workload to aquaria data centres while preventing overloading obtains network configuration strategies to determine eNB operational parameters and enables access to aquaria data centres health status.

5. PERFORMANCE FORMULATION

This section formulates the performance model for the proposed mechanism. The existing network architecture is one in which the translation intended in intent based networks is done by data centres in conventional cloud platforms accessible via the PDN-GW. This is the case found in [27]. In the proposed architecture, the translation in intent based networks is done by aquaria data centres accessible via the MME without going through the S-GW and the PDN-GW. The formulated metrics are the:

1) Network Overhead: The eNB transmits data describing subscriber QoS preferences to the cloud platform. In the existing scheme [27], the data to be translated reaches the data centre through the S-GW and the PDN-GW. There is overhead associated with transmission of data at four stages. These are: (i) eNB to the MME, (ii) MME to S-GW, (iii) S-GW to the PDN-GW, and (iv) PDN-GW to cloud computing platform. In the proposed architecture, the data transmission occurs at two stages. These are: (i) eNB to the MME, and (ii) MME to data centre.

2) Latency: In the proposed architecture, a reduced latency is associated with accessing computing resources for realizing intent based networking. This is because of a reduced number of hops in proposed architecture in comparison to existing architecture. Given that the subscriber desires to have a high channel capacity; the use of the proposed architecture enables the quick receipt of configuration information and use of transmit parameters determined to be suitable.

3) Channel Capacity: The use of the proposed architecture enables the quick realization of higher throughput via low latency receipt of configuration information.

Let $\zeta_1, \zeta_2, \zeta_3$ and ζ_4 denote the size of the control header packets transmitted from (i) eNB to the MME, (ii) MME to the S-GW, (iii) S-GW to the PDN-GW and (iv) PDN-GW to the cloud platform respectively. In addition, let ζ_5 denote the size of the control header packets transmitted from the MME to the aquaria data centre. The number of packets associated with $\zeta_1, \zeta_2, \zeta_3$, ζ_4 and ζ_5 are denoted K_1, K_2, K_3 , K_4 and K_5 respectively.

The header size associated with control packets for the existing architecture [27] and proposed network architecture is denoted Υ_1 and Υ_2 respectively and given as:

$$\Upsilon_1 = \sum_{i=1}^{5} K_i \zeta_i \tag{6}$$

$$\Upsilon_2 = K_1 \zeta_1 + K_5 \zeta_5 \tag{7}$$

In formulating the latency, this paper considers the Age of Information metric. The age of information measures the time elapsed since the last received update was generated at the source [38]. In this paper, the age of information is the time elapsed since outputs of the translation intended for the intent based network was generated at the cloud platform. The packet transmission is modelled as a discrete Ber/G/I queue.

The arrival of packets (conveying intent based network related information) occurs at time t with probability λ and associated with packet server processing rate μ. The service times are generally distributed with mean $\mathbb{E}(S) = 1/\mu$. The average peak age of information for the existing and proposed architecture are A_p^1 and A_p^2 respectively. A_p^1 and A_p^2 are [38]:

$$A_p^1 = \sum_{y \,\epsilon\, \{a,b,c,d\}} \frac{1}{\lambda_y} + \frac{1}{\mu_y} + \frac{\mathbb{E}[S^2]|_y - \rho_y}{2(1-\rho_y)} \,;\rho_y = \frac{\lambda_y}{\mu_y} \tag{8}$$

$$\mathbb{E}[S^2]|_y = \sum_{\mu_y \,\epsilon\, \{B\}} \mu_y^3 \left(1-\mu_y\right)^{x-1} \tag{9}$$

$$A_p^2 = \sum_{z \,\epsilon\, \{a,b\}} \frac{1}{\lambda_z} + \frac{1}{\mu_z} + \frac{\mathbb{E}[S^2]|_z - \rho_z}{2(1-\rho_z)};\ \rho_z = \frac{\lambda_z}{\mu_z} \tag{10}$$

$$\mathbb{E}[S^2]|_z = \sum_{\mu_z \,\epsilon\, \{B\}} \mu_z^3 \,(1-\mu_z)^{x-1} \tag{11}$$

x is the geometric factor.

Indexes $y = a$, $y = b, y = c$ and $y = d$ correspond to packet transmission between (i) eNB and MME, (ii) MME and PDN-GW, (iii) S-GW and PDN-GW and (iv) PDN-GW and cloud platform respectively.

Indexes $z = a$ and $z = b$ correspond to packet transmission between (i) eNB and MME and (ii) MME and aquaria based data centre respectively.

λ_y and μ_y are the packet arrival rate and packet server processing rate for the case in index y respectively.

λ_z and μ_z are the packet arrival rate and packet server rate for the case in index z respectively.

The number of hops is formulated considering subscriber mobility in existing and proposed architecture. In existing architecture, subscriber QoS target requests go through the path: eNB to MME to S-GW to PDN-GW to the cloud platform. This path involves four (4) hops. The path for the proposed architecture is: eNB to MME to the aquaria. This path involves two (2) hops.

Let $R_c(t_y)$ be the distance covered by subscribers at epoch t_y. The coverage diameter of eNBs within MME control is R_m. The number of hops in existing and proposed architecture are denoted N_h^1 and N_h^2 respectively. The values of N_h^1 and N_h^2 if $R_c(t_y) < R_m$ are 4 and 2 respectively. The subscriber is in the cell edge region if $R_c(t_y) = R_m$, and inter eNB handover is executed. In this case, the values of N_h^1 and N_h^2 are:

$$N_h^1 = 4 + \left(\left\lceil \frac{R_c(t_y)}{R_m} \right\rceil - 1\right) \tag{12}$$

$$N_h^2 = 2 + \left(\left\lceil \frac{R_c(t_y)}{R_m} \right\rceil - 1\right) \tag{13}$$

The number of hops is formulated for the scenario $R_c(t_y) > R_m$ considering the parameters:

1) $I_h(\varphi_{p-1}^1, \varphi_p^1, t_y) \,\epsilon\, \{0,1\}$ is the hop indicator between MMEs φ_{p-1}^1 and φ_p^1 at epoch t_y. $I_h(\varphi_{p-1}^1, \varphi_p^1, t_y) = 0$ and $I_h(\varphi_{p-1}^1, \varphi_p^1, t_y) = 1$ signifies that φ_{p-1}^1 and φ_p^1 do not and do exchange information at epoch t_y respectively.

2) $I_h(\varphi_{p-1}^2, \varphi_p^2, t_y) \,\epsilon\, \{0,1\}$ is the hop indicator between S-GWs φ_{p-1}^2 and φ_p^2 at epoch t_y. $I_h(\varphi_{p-1}^2, \varphi_p^2, t_y) = 0$ and $I_h(\varphi_{p-1}^2, \varphi_p^2, t_y) = 1$ signifies that S-GWs φ_{p-1}^2 and φ_p^2 do not and do exchange information at epoch t_y respectively.

3) $I_h(\varphi_{p-1}^3, \varphi_p^3, t_y) \,\epsilon\, \{0,1\}$ is the hop indicator between PDN-GWs φ_{p-1}^3 and φ_p^3 at epoch t_y. $I_h(\varphi_{p-1}^3, \varphi_p^3, t_y) = 0$ and $I_h(\varphi_{p-1}^3, \varphi_p^3, t_y) = 1$ signifies that φ_{p-1}^3 and φ_p^3 do not and do exchange information at epoch t_y respectively.

$$N_h^1 = 4 + \left(\left\lceil \tfrac{R_c(t_y)}{R_m} \right\rceil\right) + \left(I_h(\varphi_{p-1}^1, \varphi_p^1, t_y)\right) + \left(I_h(\varphi_{p-1}^2, \varphi_p^2, t_y)\right) + \left(I_h(\varphi_{p-1}^3, \varphi_p^3, t_y)\right) + \acute{\Gamma}_1 + \acute{\Gamma}_2 \tag{14}$$

$$\begin{aligned} \acute{\Gamma}_1 = {} & \left(I_h(\varphi_p^1 , \varphi_p^2, t_y)\right) + \left(I_h(\varphi_{p-1}^1, \varphi_p^2, t_y)\right) \\ & + \left(I_h(\varphi_p^1 , \varphi_{p-1}^2, t_y)\right) \\ & + \left(I_h(\varphi_{p-1}^1, \varphi_{p-1}^2, t_y)\right) \end{aligned} \tag{15}$$

$$\begin{aligned} \acute{\Gamma}_2 = {} & \left(I_h(\varphi_p^2, \varphi_{p-1}^3, t_y)\right) + \left(I_h(\varphi_p^2, \varphi_p^3, t_y)\right) \\ & + \left(I_h(\varphi_{p-1}^2, \varphi_{p-1}^3, t_y)\right) \\ & + \left(I_h(\varphi_{p-1}^2, \varphi_p^3, t_y)\right) \end{aligned} \tag{16}$$

$\acute{\Gamma}_1$ and $\acute{\Gamma}_2$ are hops related to data transfer between MMEs and S-GWs and between S-GWs and PDN-GWs respectively.

The number of hops in the proposed architecture is formulated considering MMEs $\varphi_{p-1}^{1}$and φ_{p}^{1} and aquaria data centres φ_{p-1}^{4} and φ_{p}^{4} and given as:

$$N_h^2 = 2 + \left(\left\lceil\frac{R_c(t_y)}{R_m}\right\rceil\right) + \left(I_h(\varphi_{p-1}^{1}, \varphi_{p}^{1}, t_y)\right) + \left(I_h(\varphi_{p-1}^{4}, \varphi_{p}^{4}, t_y)\right) + \acute{\Gamma}_3 \qquad (17)$$

$$\acute{\Gamma}_3 = \left(I_h(\varphi_{p-1}^{1}, \varphi_{p-1}^{4}, t_y)\right) + \left(I_h(\varphi_{p}^{1}, \varphi_{p-1}^{4}, t_y)\right) + \left(I_h(\varphi_{p}^{1}, \varphi_{p}^{4}, t_y)\right) + \left(I_h(\varphi_{p-1}^{1}, \varphi_{p}^{4}, t_y)\right) \qquad (18)$$

$\acute{\Gamma}_3$ is the number of hops associated with transmission between the MMEs and aquaria data centers.

6. PERFORMANCE EVALUATION

The discussion here presents the simulation results and is divided into two parts. The first part describes the assumptions and simulation parameters. The second part analyses performance benefits.

6.1 Assumptions and Simulation Parameters

The simulation examines the header size, peak age of information and channel capacity. The header control packets arising from intent based networking paradigm can be compressed with successful content retrieval. The information in these packets is separated from data packets and other control packets in LTE-A. In addition, the size of header packets (for intent based network) may exceed the size of data packets. Furthermore, packets can be added or dropped at each of these links in a random process.

The peak age of information is evaluated for different packet arrival and server rates. The service rates differ for links in the existing and proposed architecture. However, the network examined in the simulation is stable and packet arrival rates does not equal or exceed unity.

Analysis of channel capacity focuses on downlink transmission between eNB and the subscriber. The LTE-A network incorporates cognitive radio capability and accesses idle channels. Decision on accessing idle channels is driven by network configuration strategy obtained after analysis of subscriber intent based request. This computation is not done on fully utilized fog or edge nodes. In addition, delay in receiving packets and at eNB is assumed to be in the order of hundreds to thousands of milliseconds.

The simulation parameters are shown in Table 3. In Table 3, the choice of simulation parameters such as the number of eNBs between which an MME can execute inter–eNB handover assumes that the MME has modest computational resources.

Table 3: Simulation Parameters

S/N	Parameter	Value
	Packet Size Simulation Details associated with the parameters - $\zeta_1, \zeta_2, \zeta_3$, ζ_4 and ζ_5	
1	Payload Packet Size [Wu *et al.* [38]]	20 Bytes
2	Header Packet Size [Wu *et al.* [38]]	59 Bytes
3	Header Packet Size after first order compression [Wu *et al.* [38]]	15 Bytes
	Packet Processing System Details on queueing model	
4	Packet Queue Model [Tripathi *et al.* [39]]	Ber/G/1
5	Packet Queue Discipline [Tripathi *et al.* [39]]	First Come First Serve
	Network Bandwidth and Channel Configuration Details used to compute throughput	
6	LTE-A Channel Bonding Capacity	Yes
7	Subscriber signal transmit signal to interference plus noise ratio [Kachroo *et al.* [40]]	1.5 dB
8	Peak LTE –A transmit power [Kachroo *et al.* [40]]	4 Watts
9	Interference Temperature [Kachroo *et al.* [40]]	3
	Network Coverage Information used to evaluate the number of hops associated with packet transfer in N_h^1 and N_h^2	
10	MME to S –GW separating distance Xu *et al.* [41]	10 km
11	eNB coverage diameter [Aykin *et al.* [42]] R_m	16 km
12	Number of eNBs controlled by an MME	6
	Network packet server processing rates μ for each interface in the considered network	
13	Initial eNB to MME service rate	0.4
14	Initial MME to S –GW service rate	0.4
15	Initial S –GW to PDN –GW service rate	0.4
16	Initial PDN –GW to cloud platform service rate	0.4
16	Initial MME to Aquaria based data center service rate	0.4

All values of the service rate have been chosen considering that less than 50% of the network capacity is used for transmitting packets arising from the intent based networking paradigm. Challenges related to accessing the aquaria based data centers are not addressed in our discussion.

6.2 Results and Discussions

The size of the header packets is examined for existing and proposed architecture considering the cases where these packets are compressed and uncompressed. A random number of packets are considered for each link for 100 epochs. The results are shown in Figures 3(a) – 3(h). The size of header packets is examined under different scenarios considering the different average number of packets at each interface in the communication link. Interfaces in the communication link are eNB to MME interface, MME to S – GW interface, S-GW to PDN-GW interface, and PDN – GW to cloud interface. This is necessary to ensure that performance benefit analysis is not done in a greedy manner and that inference on performance analysis considers different scenarios. In addition, the simulation for the size of header packets is done assuming that packet re-transmission does not arise in the network. However, additional header information is incorporated as packets reach different network links. This is necessary for control purposes.

The results presented in Figures 3(a) – 3(h) each consider four scenarios. These are scenario 1, scenario 2, scenario 3 and scenario 4. Scenario 1 describes the case where the existing architecture is used with uncompressed packets. Scenario 2 describes the case where the proposed architecture is used with uncompressed packets. Scenario 3 considers the case where the existing architecture is used with compressed packets. Scenario 4 describes the case where the proposed architecture is used with compressed packets.

In the simulation results presented in Figures 3a–3h, packets are transmitted over 100 epochs in the network. Analysis of the results in Figure 3a shows that the use of the proposed architecture reduces size of the header files by an average of 48.8% and 96.4% with compressed and uncompressed files respectively. In addition, results in Figure 3b shows that incorporating the proposed architecture in the case of compressed and uncompressed files reduces the size of header files in the network by a mean value of 49.7% and 99.3% respectively.

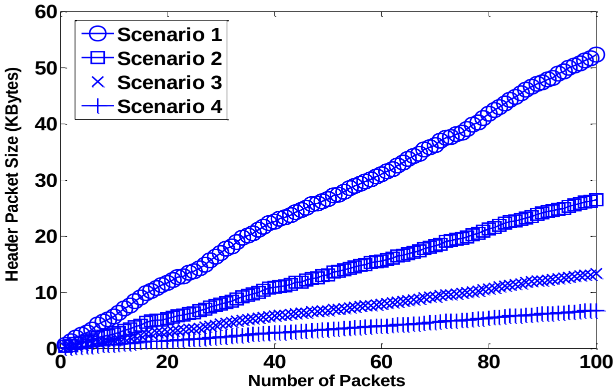

Figure 3a - First Epoch: Mean Number of Packets: eNB to MME: 4.74 packets. MME to S –GW: 5.35 packets. S-GW to PDN – GW: 5.29 packets and PDN–GW–Cloud: 4.31 packets.

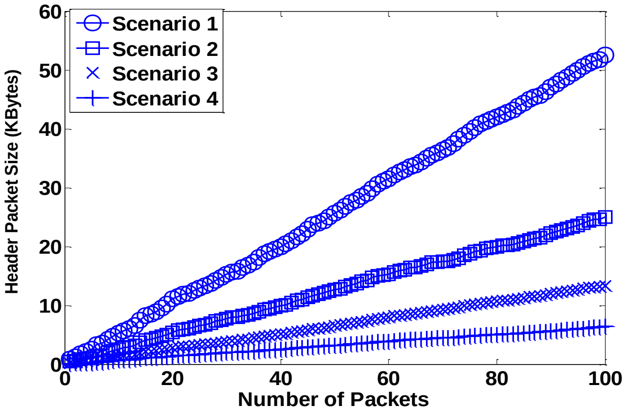

Figure 3b – Second Epoch: Mean Number of Packets: eNB to MME: 4.31 packets. MME to S –GW: 5.12 packets. S-GW to PDN – GW: 5.15 packets and PDN–GW–Cloud: 5.22 packets.

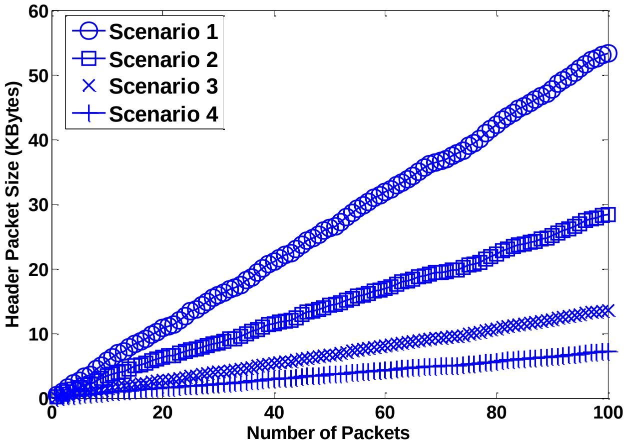

Figure 3c - First Epoch: Mean Number of Packets: eNB to MME: 5.30 packets. MME to S –GW: 5.41 packets. S-GW to PDN – GW: 5.05 packets and PDN–GW–Cloud: 4.34 packets.

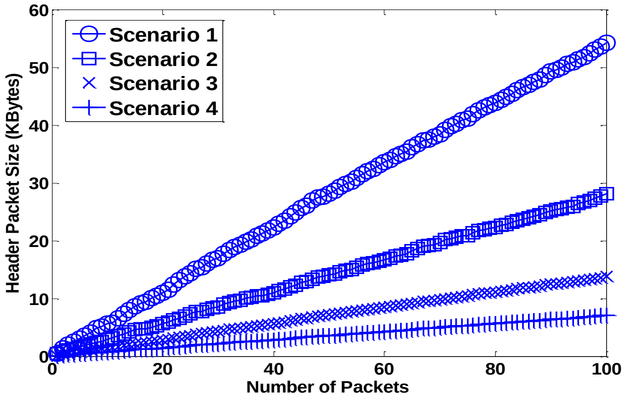

Figure 3d – Fourth Epoch: Mean Number of Packets: eNB to MME: 5.44 packets. MME to S –GW: 5.13 packets. S-GW to PDN – GW: 4.93 packets and PDN–GW–Cloud: 4.91 packets.

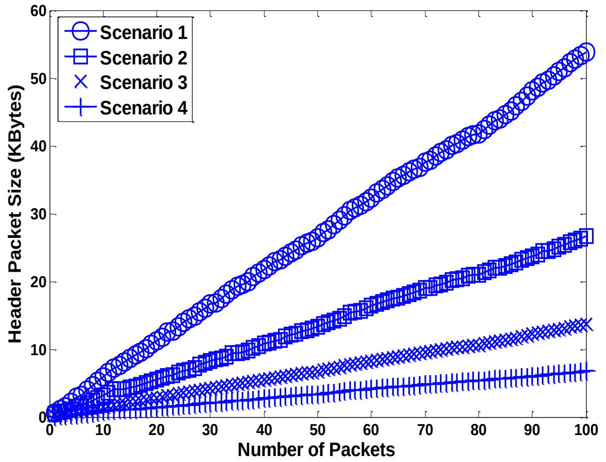

Figure 3e – Fifth Epoch: Mean Number of Packets: eNB to MME: 4.96 packets. MME to S –GW: 5.09 packets. S-GW to PDN – GW: 5.32 packets and PDN–GW–Cloud: 4.91 packets.

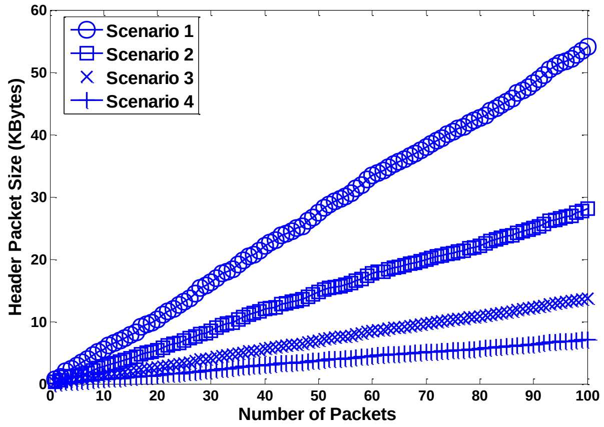

Figure 3f – Sixth Epoch: Mean Number of Packets: eNB to MME: 5.27 packets. MME to S –GW: 5.30 packets. S-GW to PDN – GW: 4.72 packets and PDN–GW–Cloud: 5.06 packets.

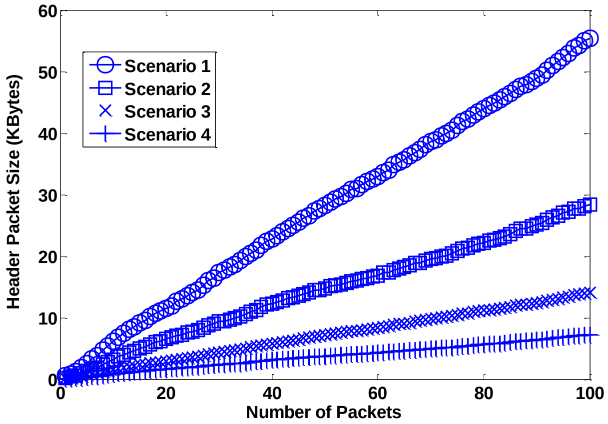

Figure 3g – Seventh Epoch: Mean Number of Packets: eNB to MME: 5.23 packets. MME to S –GW: 5.46 packets. S-GW to PDN – GW: 4.95 packets and PDN–GW–Cloud: 5.23 packets.

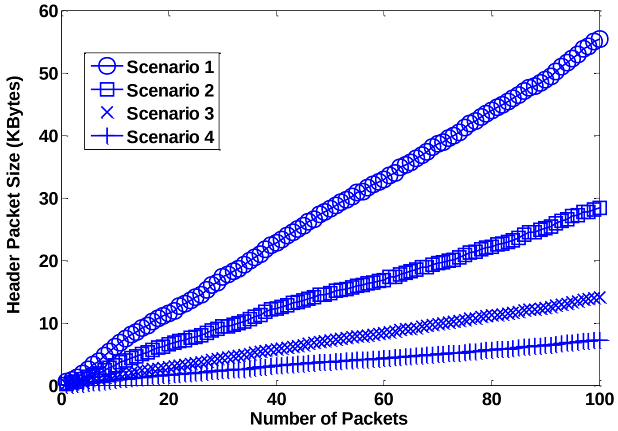

Figure 3h – Eighth Epoch: Mean Number of Packets: eNB to MME: 5.02 packets. MME to S –GW: 5.21 packets. S-GW to PDN – GW: 5.03 packets and PDN–GW–Cloud: 5.24 packets.

In addition, results presented in Figure 3c show that the use of the proposed architecture is observed to reduce the size of header files by an average of 49.0% and 96.2% respectively given compressed and uncompressed files respectively. The simulation result shown in Figure 3d shows that using aquaria based data centres (sited closer to the MME) instead of data centres accessible via the PDN – GW reduces the size of header files by an average of 49.5% and 98.3% given compressed and uncompressed files respectively.

Furthermore, the use of the proposed architecture instead of existing scheme is also shown to reduce the size of header files in the results presented in Figure 3e–Figure 3h. The mean performance improvement is denoted $\{a, b\}$ where a and b are associated with the mean reduction in header file size for compressed and uncompressed files respectively. The performance improvement for the results presented in Figure 3e, Figure 3f,

Figure 3g and Figure 3h are $\{46.3\%, 86.9\%\}$, $\{47.8\%, 91.4\%\}$, $\{47.7\%, 92.0\%\}$ and $\{49.2\%, 97.5\%\}$ respectively.

From the results in Figure 3a to Figure 3h, it can be seen that the header packet size have similar variation. This is because the packet size is fixed. In addition, the range in the mean number of packets in the eNB to MME, MME to S-GW, S-GW to PDN-GW and PDN-GW to cloud platforms links are 1.13 packets, 0.34 packets, 0.60 packets and 0.99 packets respectively. In the simulation, the MME to aquaria data centre link is similar to number of packets in the PDN-GW to cloud platform link. The header packet size has significant similarity because the differences in mean number of packets across the considered links have a close range.

Evaluation shows that the use of the proposed architecture reduces the size of header files by an average of up to 49.7% and 99.3% in the case of uncompressed and compressed packets respectively. The lower bound of the mean performance benefit is 46.3% and 86.9% for uncompressed and compressed files respectively. Therefore, the size of header files is reduced by (46.3%-49.7%) and (86.9%-99.3%) for uncompressed and compressed header packets respectively.

The latency (peak age of information) obtained by varying link service rates is shown in Figure 4.0a, Figure 4.0b and Figure 4.0c. Analysis show that the proposed architecture outperforms existing architecture and reduces the peak age of information by an average of 50.1% and 50.4% when service rates are not halved and halved respectively.

The downlink channel capacity is examined assuming that subscribers in intent based network intend to enhance their QoS by accessing idle channels to obtain improved channel capacity. The evaluation considers different packet arrival rates and peak age of information for the proposed and existing architecture. The peak age of information for packet arrival rates of 0.05, 0.25, and 0.65 are 81.8 seconds, 15.6 seconds, and 18.6 seconds respectively in existing architecture. The values for the peak age of information for packet arrival rates of 0.05, 0.25 and 0.65 are 40.9 seconds, 7.9 seconds and 11.3 seconds respectively in proposed architecture. The channel capacity for the packet arrival rates of 0.05, 0.25 and 0.85 are shown in Figure 5a, Figure 5b and Figure 5c respectively.

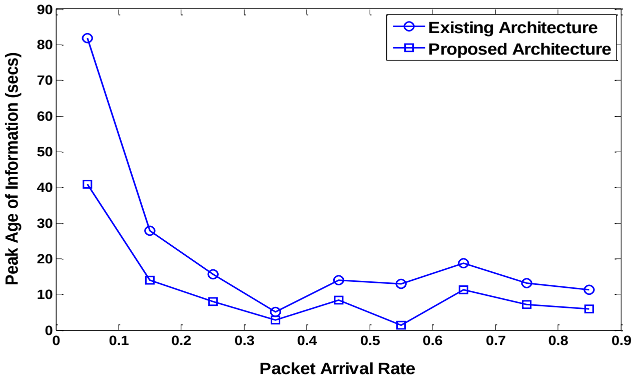

Figure 4a - First Epoch: Server Rate: eNB to MME: 0.40 packets/sec. MME to S –GW: 0.40 packets/sec. S-GW to PDN – GW: 0.40 packets/sec and PDN –GW – Cloud: 0.60 packets/sec.

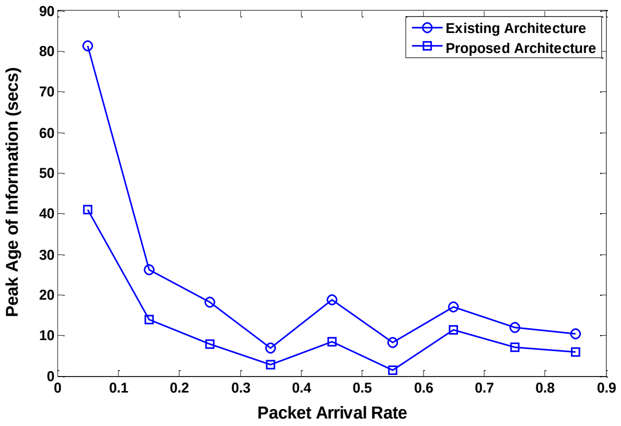

Figure 4.0b - First Epoch: Server Rate: eNB to MME: 0.40 packets/sec. MME to S –GW: 0.20 packets/sec. S-GW to PDN – GW: 0.40 packets/sec and PDN –GW – Cloud: 0.60 packets/sec.

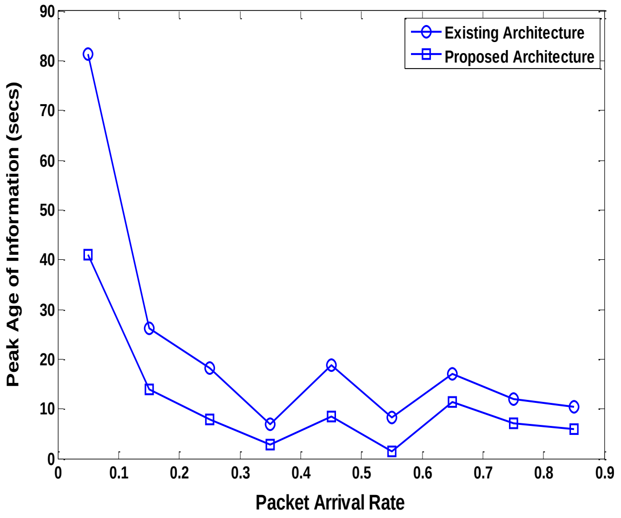

Figure 4c - Epoch: Server Rate: eNB to MME: 0.40 packets/sec. MME to S –GW: 0.40 packets/sec. S-GW to PDN – GW: 0.20 packets/sec and PDN –GW – Cloud: 0.60 packets/sec.

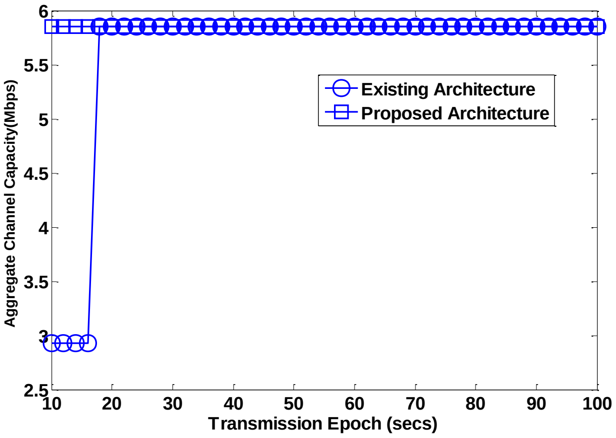

Figure 5a – Results for channel capacity given a packet arrival rate of 0.05 obtained by a subscriber on the downlink for different transmission epochs.

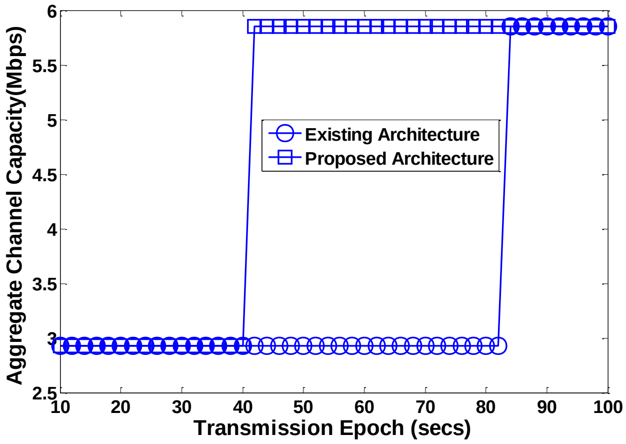

Figure 5b – Results for channel capacity given a packet arrival rate of 0.25 obtained by a subscriber on the downlink for different transmission epochs.

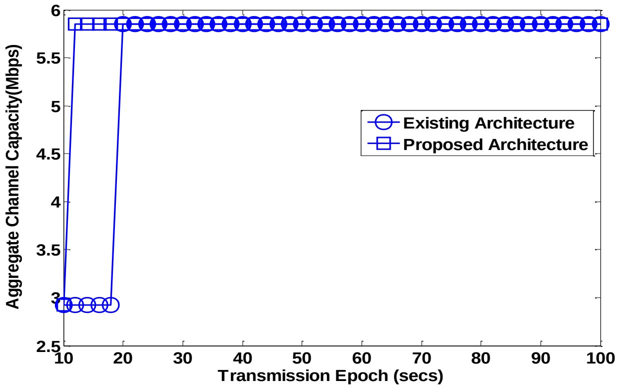

Figure 5c – Results for channel capacity given a packet arrival rate of 0.65 obtained by a subscriber on the downlink for different transmission epochs.

Analysis of results in Figure 5a, Figure 5b and Figure 5c shows that the improvement obtainable in the channel capacity is influenced by the difference in the age peak of information. This is because the simulation assumes that the subscriber maintains a constant signal to interference plus noise ratio. The use of the proposed architecture instead of the existing architecture enhances the channel capacity by 22.8%, 4.35% and 4.35% given time difference of 40.9 seconds (81.8 minus 40.9) seconds, 7.7 seconds (15.6 minus 7.9) seconds and 7.3 seconds (18.6 minus 11.3) seconds respectively.

7. CONCLUSION

This paper proposes aquaria data centres for data processing in LTE-A networks incorporating intent based networking. The use of aquaria is suitable in regions with limited maritime resources. In LTE-A, cloud platforms are accessed through the packet data network-gateway reachable via the serving gateway and mobility management entity. This path has high latency and requires more header packets. In the proposed architecture, aquaria data centers are accessed via the mobile management entity. This reduces latency and size of required control header packets. A lower latency enables a faster receipt of network configuration strategies. This enables a quicker network adaptation to improve subscriber quality of service. Performance evaluation examines size of header packets, latency (measureable by peak age of information) and channel capacity. Results show that the proposed architecture reduces control header packet size by up to 49.7% and 99.3% on average when packets are uncompressed and compressed respectively. The peak age of information is reduced by 50%. The proposed architecture enhances channel capacity by up to 22.8% on average. Analysis of power efficiency and water footprint for aquaria data centers is subject of future work.

8. ACKNOWLEDGEMENT

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