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***Abstract*—Next step of mobile is coming with 5G architecture where Software Defined Networking (SDN) will play a key role. Beyond the centralization of the control that alleviates the data forwarding task, because routing tables can be simply changed to reflect the mobile localization, we propose a new paradigm based on caching function to improve the quality of transfer during handover. Caching policy cooperates with SDN controller for automatic buffering of the data during handover. This paper also studies two caching policies that are compared through a performance analysis regarding the quality of transfer for the user and for the operator.**

***Index Terms*—Software Defined Networking, SDN Mobility, Caching Policy**

I. Introduction

Our work is in the context of mobile network architectures capable of supporting an increasing number of mobiles and integrating different access technologies such as WiFi technology.The growth of wireless devices is rapidly increasing that can be supported by the number of global mobile devices and connections in 2016 grew up from in 2015 about 5.26 percent and will be grown to 11.6 billion about 52 percent in 2021 [1]. It is possible that there is a mix of mobile/wireless devices from different factories, leading to complex management. This problem can be eliminated by Software Defined Networking (SDN) and Network Functions Virtualization (NFV) that were proposed for the future network to advance a software-based approach to networking. The leverage of SDN is a centralized network management. SDN contributes to the creation of network automation that enables a policy based decision. As NFV focuses on optimizing the network services for flexibility, scalability and cost-effective, leading to simple and fast to create new services.

The paper considers the two aspects of the software architecture, the SDN aspect and the NFV aspect with a concern for user transparency. The service is rendered in the network without the need to impact user equipment.

Concerning the use of the SDN, we implement a data relaying policy based on the location of the user. When the user moves, the SDN controller simply modifies the forwarding tables of the SDN switch. This approach has the advantage over a traditional approach based on mobility management by IP protocols, such as the PMIP approach well suited to operator networks, to avoid the use of tunnels which saves time and bandwidth. Tunnel avoidance can also be done in the traditional approach, by direct routing as soon as the source knows the location of the destination, i.e. the destination IP address. Meanwhile, security and privacy objectives considerably increase the mobility management complexity. The implementation of the approach, which we have explained in [2], is based on access switches signaling to the controller, through OpenFlow protocol, the location of the mobiles they discover instead of using the traditional mobility signaling (the PMIP messages) to indicate to a mobility agent the location of the users.

The SDN approach improves the operation of the network as the loss rate is decreased thanks to the simplification of the mobility control. However, the data transfer service suffers from losses when changing mobile access points. To solve this problem, we propose an innovative approach that improves the service by adding a caching function to the SDN equipment. The purpose of this function is to memorize given contents for a given time. In this paper, we show the interest of such a function on the SDN equipment and study the parameters of the caching policy to answer the questions: which content to cache? For how long?

The present, network caching such as Content Delivery Network (CDN), Information Centric Networking (ICN), Content-Centric Networking (CCN), and Name Data Networking (NDN) use cache techniques to gain more performance such as reducing the latency and traffic load. Even though many traditional network caching were proposed, their concept is based on caching all of the popular requested content and requires some special configuration or software installation at users.

The originality of our approach is to propose: 1) a transparent caching to the user that does not require to modify the user equipment, 2) a caching that is function of the network state and not the application, there is no need for content to be popular to be cached, it will be if the network state is of poor quality, 3) caching takes place on certain parts of the content and not all the content.

This paper proposes to use caching policy with SDN Mobility approach for improvement regarding the packet loss. The caching duration is based on the network quality evaluation with various policies. Two caching schemes, ON OFF caching and Adaptive caching, are introduced and compared in terms of user quality and operator quality. We evaluated, by simulation, the transmission time, the occupancy time, and the fairness for mobile users and fixed users.

The rest of this paper is organized as follows: the related works are introduced in Section II, SDN mobility with caching policy is described in next section. The experimental topology and performance analysis are shown in Section IV and Section V; then Section VI draws the conclusion concerning the interest of caching a given content.

II. Related Works

Caching techniques are widely used for different reasons to improve the network efficiency such as for reducing latency, the traffic load on centralized data centers and gateways, and energy consumption (EE) in wired networks and for improving Spectral Efficiency (SE) and EE in wireless networks [4][5].

For the future Internet architecture, such as CCN, and NDN, the built-in network cache has been used to improve the transmission efficiency of the content dissemination, reduce the network traffic, alleviate bottlenecks, and reduce the user access latencies. Also, network caching is better than the traditional Web Caching and Content Delivery Networks (CDN) such as transparent cache, cache ubiquity, credibility and safety [6] [7] [8].

G. Ma and Z. Chen [8] have compared the content delivery capability of CDN and CCN regarding transmission time in three experiments. The results have shown that the transfer time of CCN is better than CDN when the number of clients is increasing. Meanwhile, CDN gives the higher performance than CCN with the bandwidth increasing and the number of transport increasing.

OpCachMob [9] is an optimal caching scheme for producer mobility supported in NDN. OpCachMob concept allows caching the data before handover occurs based on Gurobi model [10] for finding the best placement. The results have shown that OpCachMob is better than pure NDN regarding the consumer delay but worse concerning overhead percentage.

Even though, [8] and [9] use caching schemes to cache popular contents for improving network performance, [8] did not consider mobility. As [9] focused on mobility management in NDN network, but requires some software installation at the mobile node, leading to heavy usage, actually in practice.

Also, Software-defined Networking (SDN) can be applied to manage the network caching in both the legacy and future systems. A Software Defined Controller for CCN (SDC-CCN) [11] is a mobility management scheme which was designed based on the concept of SDN for allowing flexible packet forwarding and focusing on the content source mobility. The results from analysis model have shown that SDC-CCN can be improved, regarding the transmission overhead, in both wired and wireless network, compared with the existing approaches such as the Indirection Point Scheme (IPS), the DNS Server Scheme (DSS), Tunnel-Based Redirection (TBR), the Locator-Based Scheme (LBS), and the Data and the Control Plane separation scheme (DCP).

Software Defined Mobile Network (SDMN) [5] was proposed to optimize caching in LTE mobile network by integrating SDN with Mobile Management Element (MME). The GTP mobile tunneling can be removed and it also allows dynamic relocation of the cache by SDN usage.

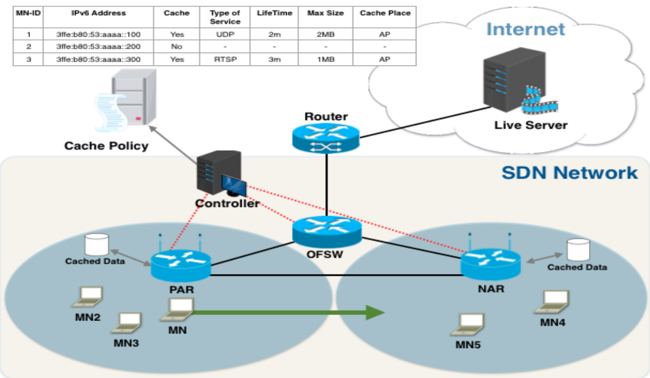

Fig. 1. SDN Mobility with Cache Policy Architecture

N. Zhang and al. [12] have compared by using simulation, the SDN-optimized in LTE network caching system [5] with In-network caching in term of traffic load, capital expenditure (CAPEX), and operational expenses (OPEX). The simulation results have shown that in-network caching reduced traffic load about 45% in the network and 6% in the gateway. The cost modeling in the network caching reduced network-related CAPEX about 1.53% and OPEX about 0.49 % compared with the data center caching.

[5] and [12] were proposed for LTE network and [11] focused on the content source mobility. In this paper, we consider WiFi networks and destination mobility, and we propose another way for improving the performance by using the caching policy with SDN architecture.

III. Proposed Approach

Caching is a mechanism for storing data. It can be classified into two broad categories: proactive caching and reactive caching. The proactive caching approach is one caching method that guarantees no packet loss during MN handover; the data packets will be stored all the time, whether the MN stays or moves from a network. Reactive Caching works only while the MN had the movement event that is an interesting point to improve by decreasing the number of packet loss and saving the storage. Therefore in this paper, we adopt a reactive caching policy with an SDN approach for IP mobility management in the network. The additional caching operation is managed by the SDN controller based on caching policy.

A. SDN Mobility with Caching Policy Architecture

First of all, let us expose our management of mobile users by SDN architecture. There are three main components: the controller, the Access Router (AR), and the Caching Policy as illustrated in Fig. 1.

1) SDN Controller: It is an OpenFlow controller which locates in the same network as ARs. Its duty is to be responsible for the flow table to all ARs in the network and to organize the cache events based on the caching policy. To allow the caching management to support moving nodes, the SDN controller needs to record the cached information of each mobile node as shown in TABLE I.

TABLE I
THE CACHED INFORMATION IN SDN CONTROLLER

Parameter	Description
MN-ID	Mobile Node identification.
SrcAddr	An IPv6 source address.
DstAddr	An IPv6 destination address.
CacheStatus	Specifies status of cache, YES means the content is cached.
ToS	Specifies type of traffic.
PAR	Specifies the previous access router.
CurAR	Specifies the current access router.
CachedPlace1	Specifies the place which stored the content.
CachedPlace2	Specifies the place which stored the content. In case, MN moved and attached more than one AR.

2) Access Routers (ARs): ARs are the OpenFlow switches located on the access network. They are responsible for the movement of the mobile node and the OpenFlow messages exchange with its controller. All ARs support caching operation and coordinate with OpenFlow command messages with the controller. In the following, we distinguish the Previous Access Router (PAR) from the New Access Router (NAR).

3) Caching Policy: A caching policy defines rules for caching the requested content of each MN. It can be installed either on the SDN controller or the other servers. SDN controller can get the rule of each mobile node from the caching policy through Application Programming Interface (API).

SDN controller uses a caching policy to determine which mobile requires to cache the requested content. Caching parameters, that are shown in TABLE II, will be sent to PAR or NAR after the mobile attached for caching configuration of the mobile.

Once the architecture is established, the problem is to define the proper caching parameters and especially the caching duration. We consider that the duration of caching is defined by the quality of the network. We postulate that when the mobile moves such as the quality of its link to the access point is deteriorated the access point has an interest in keeping the information rather than in transmitting to it. Mobile will receive its cached data upon a better access quality event. More precisely, we propose two caching policies: ON-OFF and Adaptive caching policy. Both policies will start to cache the packets after a cache trigger is enabled. In the ON-OFF caching policy, the packets will be cached and non-forwarded while the mobile node stays in a low bandwidth area. But the Adaptive caching policy still forwards the packets to the mobile node with an adaptive rate and will stop to forward the packets during the handover. The adaptive forward rate can be calculated from the physical rate of the mobile node position multiplied by the proportion of useful throughput [13] which varies according to the total number of active nodes associated with that access point.

B. Cache Operation

1) Cache Trigger: We have simulated a simple wireless topology, by NS3, to determine the characteristics of WiFi in regarding throughput and distances by varying the data rate and the mobile node position. The results, in Fig. 2, show that when the mobile moves far away from an access point, its throughput capability is reduced. So this contrast is used for enabling cache trigger. In this paper, we define the "good bandwidth" area, as a zone that allows the received data rate of the mobile node, to be equal to the transmitted data rate.

TABLE II
THE PARAMETER OF CACHING RULES

Parameter	Description
MN-ID	Mobile Node identification.
MN-IPv6	An IPv6 address of MN.
CacheOp	Specifies YES value, cache requirement for that MN.
ToS	Specifies type of traffic which requires to cache.
ExpTime	Specifies the expiration of cached data.
MaxSize	Specifies maximum size of cached content.

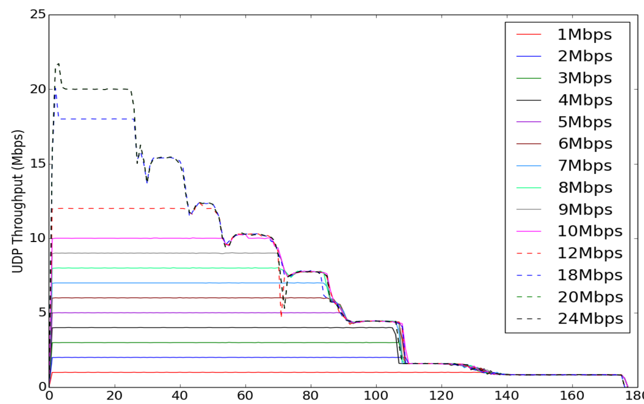

Fig. 2. Throughput vs Distances

2) NS3 Implementation: We have created a new class which is named "CacheApWifiMac" class, to add to the access points capability to support caching operation. CacheApWifiMac class inherits from ApWifiMac class of NS3 WiFi module. The packet classification and caching operation have been implemented in this class. These operations will be done at the MAC level of the WiFi model in the access points. Therefore, when the packets of mobile nodes are forwarded to the MAC high level, they will be classified specifically for mobiles based on caching policy and will be enqueued to a specific queue of each mobile. The packets will be dequeued and forwarded down to MAC low level for transmission while the forward state of the mobile is true.

C. SDN Mobility with Cache Policy Operation

The overall functioning of our architecture is as follows. Mobile Node (MN) process can be separated in two procedures: MN registration and MN handover. The OpenFlow messages are exchanged between the controller and ARs for notifying of the MN arrival, for updating the routing path, and for additional caching options. The SDN Mobility with cache policy signaling is illustrated in Fig. 3.

1) MN Registration: When the MN enters the network, PAR detects the attached event and sends an OpenFlow message to its controller for informing this event. Once the controller receives and processes that message, it requests the caching policy of the MN from the cache policy server. After that, the SDN controller sends the OpenFlow messages to all ARs for adding the routing flow of the MN and sends an OpenFlow message to the PAR for enabling the caching mode of the MN. Then, the Correspondent Node (CN) directly communicates with the MN. Note that, we assume that the controller has the network policy allowing the MN to access the network and a caching rule of the MN.

If the MN is communicating and moving simultaneously far away from the PAR, the ability of received data rate of the MN changes. If the difference of data rate is higher than a given threshold, the cache trigger is enabled. For the Adaptive caching policy, the PAR starts to cache the packets of the MN and adapts the forwarding rate to send the cached packets to the MN. The PAR caches and stops to forward the packets of the MN in the ON-OFF caching policy. At the same time, the PAR sends an OpenFlow message to its SDN controller for informing the data of the MN has been cached at PAR. Then SDN controller updates its cached information.

2) MN Handover: For Adaptive caching policy, when the MN detaches from the PAR, the PAR stops to forward the packets of the MN. After the MN completely registers with the NAR and received a forward cache command from the controller, the PAR forwards all cached packets to the MN directly.

For the ON-OFF caching policy, the PAR will forward the cached packets when the MN moves in the good bandwidth area. Meanwhile, the SDN controller sends an OpenFlow message to the NAR for caching and stops forwarding. The new packets of the MN are cached at the NAR. After the PAR has finished forwarding all cached packets, it informs the controller of this event. The controller updates the cached information and advertises to the NAR to directly forward the new cached packets to the MN. Note that, the MN attached/detached event can be done in layer two by using IEEE 802.21 Media-independent Handover (MIH) or OpenFlow-specified.

IV. Experimental Topology

We set up an experimental network with cache policy that consists of the main components as illustrated in Fig. 1. Two network architectures have been considered: overlapping network (Net1) and no-overlapping network (Net2). In the overlapping network, the distance between PAR and NAR is 260 meters and is 355 meters for no-overlapping network. These architectures have been chosen because, after MN handover, MN lives in the different bandwidth areas and takes different handover delay. So, we can study how it impacts: 1) the User Quality of Service (U-QoS), determined by transmission time, loss and jitter and 2) the Operator Quality of Service (O-QoS), determined by channel occupancy time and fairness index.

The percentage of packet loss in the wireless network depends on the velocity of the MN and the traffic data rate of the MN. From [2], the number of packet loss will significantly increase when the velocity of the MN is less, and the traffic data rate is higher or equal than 0.9 Mbps, due to WiFi loss and handover loss. Meanwhile, only handover loss appears at a data rate less than 0.9 Mbps. To experiment a lossy network context, we focus on the movement speed for walking, MN speed equal to 1 meter per second, and use a data traffic higher than or equal 1 Mbps.

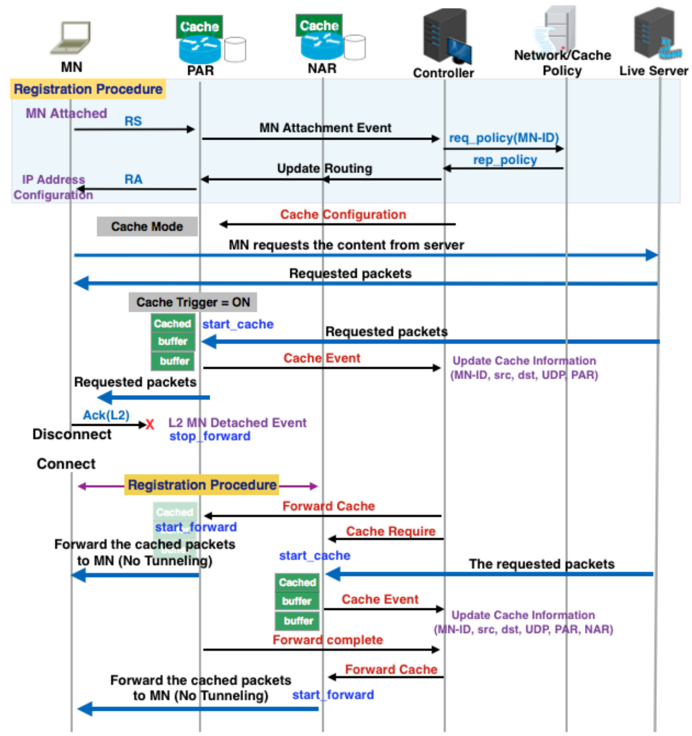

Fig. 3. SDN Mobility with Caching Policy Signaling

V. Performance Analysis

This section shows the experimental results and analysis. The experimental topology was setup as described in the previous section. In both networks, we measured the performances in two cases; single MN traffic and multiple MNs traffic. The same configured parameters are set in each network for measuring the performance with different caching policies. Each simulation with No-cache, ON-OFF caching policy, and Adaptive caching policy has run ten times. The results are obtained by averaging.

A. Case 1: Single traffic MN

With this first traffic case, we show the usefulness of the caching mechanism. We are not only interest in the quality of service which is provided to the mobile user but also to the impact of the scheme at the network level, a mechanism that would increase the bandwidth occupancy would cause a problem of network efficiency since the network supports several devices.

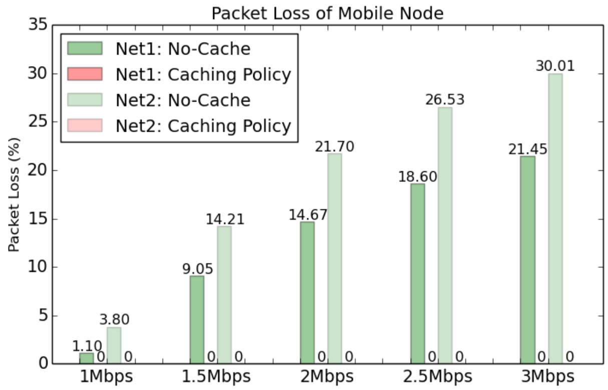

Fig. 4. Percentage of Packet Loss in Single Traffic MN case

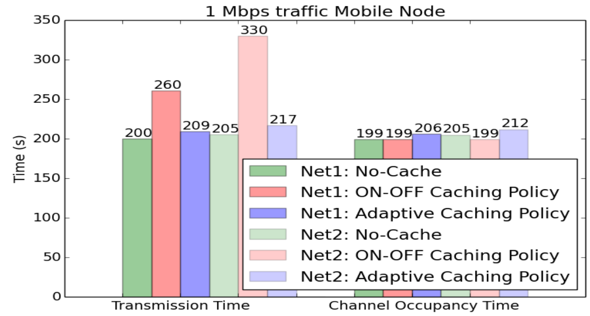

Fig. 5. Transmission Time and Occupancy Time of Single Traffic MN.

In both overlapping and non-overlapping network. The MN is generated and set to the position (0,0) from the AP. The mobility model of the MN is constant velocity at speed 1 metre per second. The MN receives a CBR UDP traffic that is generated from a live streaming server for 200 seconds. The UDP datagram size is set to 1400 Mbytes.

1) U-QoS: We evaluate the percentage of loss and the transmission time.

Packet Loss: The results, as shown in Fig. 4, indicate that both ON-OFF and Adaptive caching policy eliminates the packet loss at all data traffic rates. Note that, as expected the percentage of packet loss with No-cache in Net2 is higher than in Net1, because Net2 takes handover time more than Net1 and MN spends a long time in the weak bandwidth area.

Transmission Time: The transmission time to the MN is illustrated in Fig. 5. The results show that the transmission time of the ON-OFF policy is highest in both networks. About 30% and 62.5% higher than No-cache policy in Net1 and Net2. These results are caused as the ON-OFF policy, is forwarding the packets only in situations where the MN is living in the good bandwidth area. Then, the transmission time of the ON-OFF caching policy is depending on the network topology and moving pattern of MN. The Adaptive caching policy takes a higher transmission time than No-cache policy (about 4.5% and 5.85% in Net1 and Net2). Indeed the Adaptive caching policy degrades the forwarding data rate while the MN lives in weak bandwidth area for avoiding packet loss.

From the results, we can conclude that U-QoS is improved by caching, there is no loss. The cost regarding delay depends on the caching policy. The Adaptive caching policy seems preferable.

2) O-QoS: Considering the channel occupancy time of each network as shown in Fig. 5, the occupancy time of the ON-OFF caching policy in Net1 is equal with No-cache policy but less than in Net2 about 2.9%. In this network, the MN lives in the weak bandwidth area (the ability of a received data rate less than the transmitted rate) after the handover. Then some packets are buffered in the access point, leading to cost more delay than in No-cache policy. But the ON-OFF caching policy forwards packets only in good bandwidth area, (the transmitted data rate equals to the received data rate). Therefore the ON-OFF caching policy doesn't buffer packets in the access point, leading to the same occupancy time in both networks.

For the Adaptive caching policy, it takes a higher occupancy time than the No-cache policy (about 3.5% and 3.4% in Net1 and Net2). Indeed, the Adaptive caching policy degrades the forwarding data rate depending on the MN position, the packets are cached. These cached packets will cost more in terms of the occupancy time.

To conclude, with caching, packets are transmitted more rapidly but more packets are transmitted (there is no loss) resulting in quite the same occupancy time for caching and non caching method. There is no O-QoS degradation.

B. Case 2: Multiple Traffic Nodes

We increase the number of traffic nodes to degrade the network quality and to consider the impact of the proposed policies over other nodes. The UDP traffic rate of each node is set equally. The MN is generated and set at position (0,0) from AP; its mobility model is constant velocity, 1 metre per second. The other nodes are stationary nodes. Their positions are set in the good bandwidth area, away from the AP about 1 meter to 5 meters.

1) U-QoS: **Packet Loss:** The percentage of packet loss is shown in the Fig. 6. Considering No-cache policy, in conformance to result of [13], the packet loss of stationary nodes significantly increases when the number of traffic nodes is high on both networks. Because, while the MN is moving far away from the AP, the MN may encounter bad transmission conditions, leading to the possibility of high packet loss. When the AP transmits a packet to the MN if the AP does not receive the layer two acknowledgement from the MN, the AP will retransmit the lost packet. Therefore, the traffic of the MN occupies the radio channel more than the other nodes, leading to the performance anomaly: the other nodes lose more packets, because of retransmission. But for both Adaptive and ON-OFF caching policies this problem does not occur because they stop forwarding the packets before the MN handover, leading to gain a fewer loss that caused by WiFi loss of the MN movement.

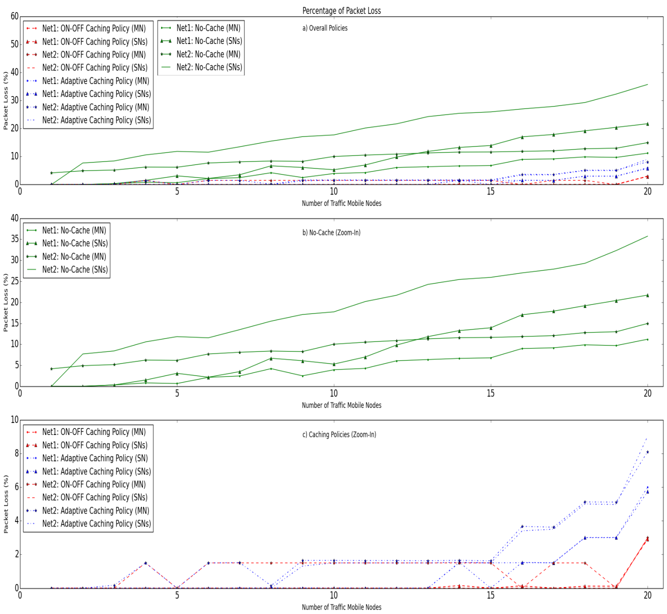

Fig. 6. Percentage of Packet Loss in Multiple Traffic MNs

Packet Interval Time and Transmission Time: For visibility reason, we present results for two nodes. We obtained similar results with more nodes. The MN starts to move from the initial position (0.0) far from the AP and will approximately handover at second 175. The packet interval time of the MN and stationary nodes of both networks are shown in Fig. 7 and Fig. 8. For, the first period, second 0 to second 25, the interval packet of each policy is close to one sent by the source (CN). Then, the interval packet is spread when the MN is moving further away from the AP, caused by the possibility of high packet loss from the MN movement and the distance of the MN. The AP retransmits the MN packets, and the packets of stationary nodes are buffered at the AP, for sending after the channel becomes idle.

During the handover, the AP should serve the stationary nodes, but the results of No-cache policy, in both networks have shown that fewer packets have been sent to stationary nodes. Because the AP tries to retransmit the MN packets, blocking the traffic of stationary nodes, it leads to unfairness. For Adaptive caching policy and ON-OFF caching policy, the AP serves only the traffic of stationary nodes, because both policies do not forward the MN packets in this duration.

After MN attached the new AP (NAR), No-cache policy and Adaptive caching policy continue to send the MN packets, but ON-OFF caching policy starts to forward in Net1 and will forward later, when the MN lives in the good bandwidth area, for Net2.

Considering the packet interval of the stationary nodes, after the MN handover, the results of ON-OFF policy are close to those sent by the CN. From this results, we see that the MN movement effects the traffic of the other nodes while the MN is moving in the weak bandwidth area.

The packet interval time of Adaptive caching policy is quite

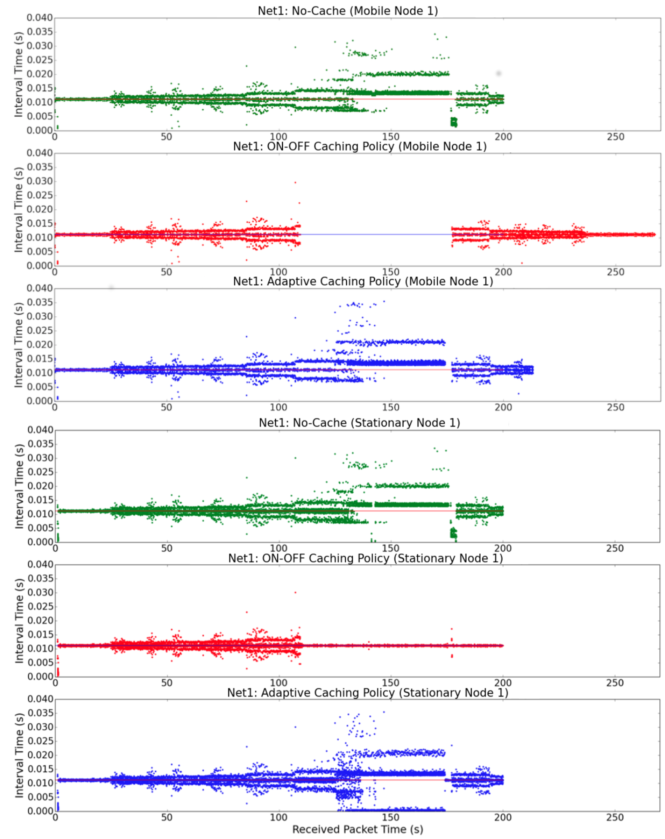

Fig. 7. Interval Time of Mobile Node and Stationary Node in Net1.

similar to the No-cache policy one in both networks. But the transmission time of the MN with the Adaptive caching policy is slightly higher than with the No-cache policy about 4.5% and 6.5% in Net1 and Net2.

Considering the packet interval time, the ON-OFF caching policy is better than the No-cache policy and the Adaptive caching policy for both MN and stationary nodes. But ON-OFF caching policy is worse regarding transmission time of the MN. This cost is higher than No-cache policy about 35% and 72.5% in Net1 and Net2. The transmission time of the MN in the two nodes case is higher than the one MN case about 3.8%, due to the WiFi bandwidth sharing.

2) O-QoS: **Bandwidth Fairness:** We examine the sharing of the bandwidth between several users (1 to 20 users) by using Jain's fairness index on bandwidth occupancy as illustrated in Fig. 9. The results of Adaptive caching policy are better than No-cache policy ones whatever the number of traffic nodes. But the ON-OFF caching policy gives high bandwidth fairness as the number of traffic nodes is high. Because of the ON-OFF caching policy sends the packets only where the MN lives in good bandwidth area, it takes more transmission time, then the average of bandwidth is low.

We can synthesize the results presented in this section by stating that the caching time which depends on the quality of the network and the Adaptive caching policy affects the quality of the user service but also that of the operator insofar as the

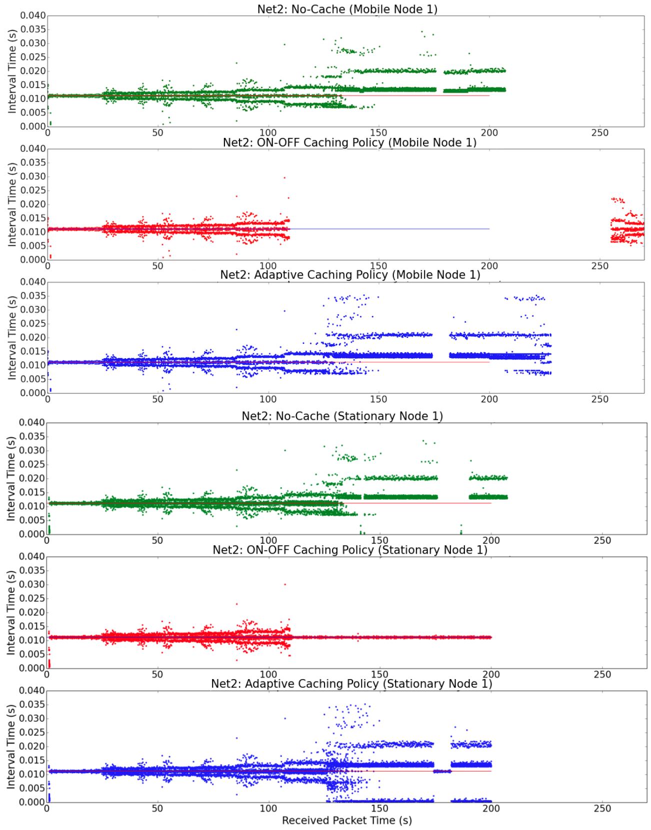

Fig. 8. Interval Time of Mobile Node and Stationary Node in Net2.

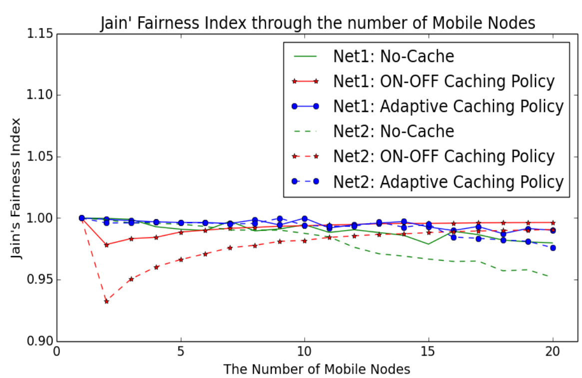

Fig. 9. Jain's Fairness Index through the number of traffic nodes

service may be unfair. A significant caching time but with a fast transmission, as implemented in the ON-OFF policy, improves the operator quality to the detriment of the user quality. A shorter caching time but with a higher transmission rate, as proposed by the Adaptive caching policy, gives an opposite effect.

VI. Conclusion and Future Work

In this paper, we have proposed to use the cache policy with SDN Mobility approach for providing IP mobility management that can eliminate or minimize some packet loss in SDN mobility network. Two caching policies have been proposed, the ON-OFF caching policy and the Adaptive caching policy. Their performance analysis has been measured regarding the percentage of packet loss, transmission time, channel occupancy time and bandwidth fairness. According to the obtained results, we can conclude that both proposed cache policies can improve SDN mobility regarding packet loss. Even though, the ON-OFF caching policy is worse concerning transmission time but good regarding the channel occupancy time. Then the ON-OFF caching policy is suitable to be used with the applications which are non-sensitive to the delay such as file transfer or some media applications which download all contents before display. For delay sensitive applications, Adaptive caching policy is properly used. Even though, the transmission time of the Adaptive caching policy is a bit higher than than No-cache policy. But this weakness will not affect for actual usage because the general media display applications buffer the video before display. It would be interesting to evaluate our proposed schemes and compare them to the caching mechanism proposed by adaptive HTTP.

The caching mechanisms we have proposed are made possible by the software implementation of the network. We have shown their interest, the following work concerns their exploitation, considering the caching function as an NFV deployable on-demand, depending upon the topology, in one or more instances function of the caching policies and the traffic data rate.

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