Local Area Data Network for 5G System Architecture

Jicheol Lee, Sang-Jun Moon, Beomsik Bae, and Jinsung Lee
Samsung Electronics
Suwon, Republic of Korea

***Abstract*— We introduce a noble concept and design of Local Area Data Network (LADN) that geographically isolates the operator network resources to provide high data rate, low latency, and service localization for 5G System Architecture. In addition, we compare two alternative solutions of handling the LADN session with considerations of UE power consumptions and human mobility patterns. The proposed LADN technology enables the edge computing.**

***Index Terms*—5G System Architecture, Edge Computing, Local Area Data Network.**

I. Introduction

5G System Architecture is currently being standardized under 3GPP SA WG2. Compared to Evolved Packet Core (EPC) for 4G Network, 5G System is more flexible to be tailored for data center environments and provides virtualization, stateless network functions, service-based interfaces, and network slice as key characteristics of 5G System [1]. For 5G core networks, the data centers can be either in distributed and centralized manner. When the data centers are deployed in distributed manner, the operator can efficiently offload traffic and easily provide edge computing service to realize the 5G application with low latency and high data rate requirements.

We proposed a noble concept of Local Area Data Network (LADN) as an enabling technology for supporting edge computing [2]. The proposed concept is to provide a Data Network connectivity service to the UE by geographically isolating the operator's network resources.

In this paper, we introduce the proposed concept of LADN and its usage scenarios in section II. We explain the overall design of the LADN solution in section III. We compare and analyze the two solution alternatives to realize the LADN concept with considering human mobility model in section IV. We explain our simulation setup in section V and we explain and analyze simulation results to compare the two solution alternatives in section VI. We conclude in section VII.

II. A Concept of Local Area Data Network

In this section, we introduce a noble concept of the LADN, its usage scenarios. At the end of this section, we explain the difference from the earlier work (i.e Local IP Access) to help the readers familar with 3GPP Evolved Packet System understand the proposed concept easily.

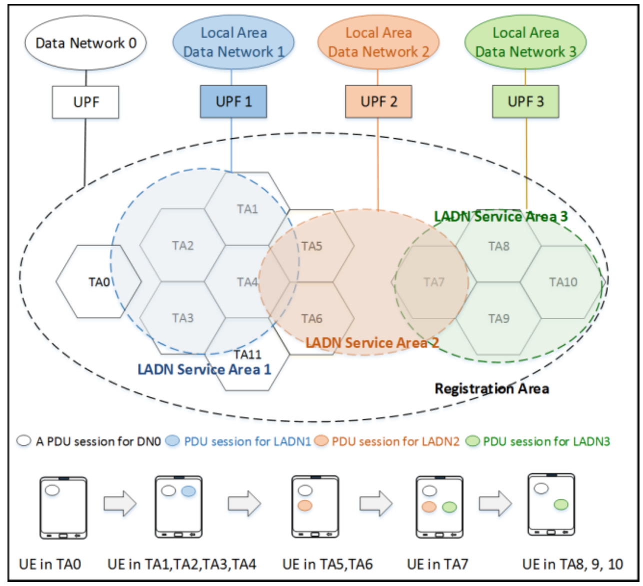

Fig. 1. A concept of Local Area Data Network

A. Concept

A Local Area Data Network (LADN) is a Data Network to which the UE can connect with a LADN session only when the UE is located in a certain area, which was proposed in [2]. When the UE establishes a LADN session, the network allocates a new IP address/prefix to the UE for connecting the LADN while the existing Packet Data Unit (PDU) session(s) is/are still maintained.

Figure 1 shows the proposed concept of the LADN. A UE can establish a PDU session 1 through UPF1 to connect LADN 1 when the UE is located in LADN service area 1 as shown in blue color. When the UE is located outside of the LADN service area 1, the UE is not allowed to connect LADN 1. The LADN service area is agnostic to the registration area. For example, within one registration area (i.e. as depicted in a black dotted oval), there are multiple LADN service areas (i.e. as depicted in blue, orange and green ovals). It is allowed that LADN service area 2 and 3 have an overlapped area (e.g. TA7) as in Fig 1.

B. Usage scenarios

Using the proposed LADN concept, we can realize the four usage scenarios as described in [2].

First, LADN realizes 5G applications with low latency and high data rate since an operator can locate the dedicated User Plane Function near RAN. For stadium scenarios, a streaming service with low latency and high data rate is provided only to the customers who are watching the sports in the stadium. For example, a free-view point video streaming that requires less than 1 millisecond latency and more than 100 Mbps per user for a stadium service.

Second, LADN supports the enterprise campus scenario, since it is able to restrict the IP connectivity for the employees for the company who are authorized to access the local enterprise servers if they are located in the campus area.

Third, LADN supports the shopping mall scenario since it is able to provide the customers sponsored IP connectivity to the customers who are visited the shopping mall where they are located in the shopping mall area.

Fourth, LADN supports the special event scenario (e.g. a concert) since it is able to offload the subscriber's increasing data traffic that is coming from a localized area where the special event takes place.

C. Differences from Local IP Access (LIPA)

We note that the proposed concept is different from Local IP Access (LIPA) defined in [3], [4], and [5] since the LIPA relies on the Closed Subscriber Group (CSG) and the RAN's awareness while the proposed concept does not. Another difference is that in LIPA, one CSG cell belongs to only one CSG group for LIPA connection while one cell within a TA can belong to the multiple LADN session. Since the LADN does not require the change of RAN configuration to launch a new LADN service, we think this aspect is one of advantages of the proposed LADN concept. Using this flexibility, operators can dynamically configure a LADN service area when new LADN service area is required for a new service.

III. Design of Local Area Data Network

To explain the LADN design, we first brefly explain the 5G System Architecture described in [1]. In 5G System Architecture shown in the Fig 2, the Access and Mobility Management Function (AMF) is responsible for registration and connection management functions. The Session Management Function (SMF) is responsible for establishment, modification and release of PDU session including tunnel management between the (R)AN node and the User Plane Function (UPF). The UPF is resposible for downlink packet buffering and downlink data notification triggering in addition to packet routing and forwarding. These functional description are described in [1].

The LADN is designed on top of 5G System architecture. The LADN service area is configured at AMF. The SMF is resposible for handling the PDU session for the LADN.

In the remaining of this section, we describe the LADN designs, i.e. configuration of LADN service area, how the UE discovery of the LADN information and establishment, movement of the UE crossing LADN service area boundaries and termination of the PDU session for the LADN.

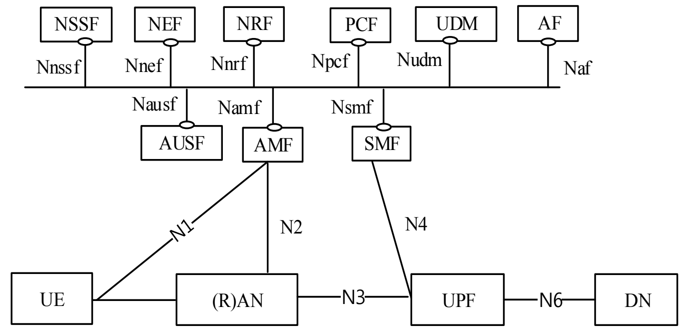

Fig. 2. 5G System Architecture [1]

A. Configuration of LADN service area

After the operator plans the LADN service, it configures the LADN information, which consists of the Data Network Name (DNN) and LADN service area (e.g. a set of TAs).

B. Discovery of the LADN information

The 5G Core Network notifies the UE of the LADN information that are available to the UE, based on the UE location. When the UE first registers to the network within the registration area, if the registration area contains the LADN service area, the network (i.e. AMF) informs the available LADN Data Network Name (DNN) with it available tracking areas to the UE.

C. Esstablishment of PDU session for LADN

Based on the information, the UE may request a PDU session establishment for an available LADN based on the UE application request only when the LADN is available.

D. UE Movement crossing LADN boundaries

When the UE moves out the LADN service area, the UE is not allowed to use data services with the peer entity in the LADN data network. When the UE is out of the LADN service area, the network changes the PDU session reachability state to unreachable. In the PDU session unreachable state, the UPF drops the data packets since the UE is not allowed to send and receive the data packets outside of LADN service area.

To manage the PDU session's reachability, there are two alternatives. In first approach, the UE does not report its location whenever it crosses the boundary of LADN service area. When the downlink data comes to the network, the network wakes up the UE to identify whether the UE is inside or outside of LADN service area. In second approach, the UE reports its location by performing the mobility registration procedure whenever it crosses the LADN service area boundaries. We analyze both solutions in section IV.

E. Termination of PDU session

The network may at any time, based on the network policies, release the PDU session.

IV. Solution Alternatives

As briefly described in the previous section, there are two alternatives solutions. In order to analyze them, we describe both solutions in this section.

A. Solution A: No Reporting when Crossing LADN boudary with false paging (NRCL)

With this approach, the UE does not report its location whenever it crosses the boundary of LADN service area. The network is aware whether the UE moves into or out of LADN service area when the UE is in CM-CONNECTED state. However, the UE moves into or out of LADN service area in CM-IDLE state, the network does not know whether the UE is inside or outside of the LADN service area. Therefore, when the downlink data comes to the UPF for LADN, the network performs the paging procedure. After the UE wakes up, the network can determine whether to drop the buffered packets based on whether the UE is located inside or outside of the LADN service area. In this scenario, if the UE is outside of the LADN service area, the network drops the packet. We call this unnecessary paging operation as *false paging* in solution A.

The advantage of this solution is that the UE power consumption does not increase since the UE does not perform the mobility registration procedure to report its location when it crosses the boundary of LADN service area.

The disadvantage of this solution is that the network should perform the paging procedure to wake up the UE even when the UE is located out of LADN service area. After the UE wakes up, the UE stays in CM-CONNECTED state until the inactivity timer expires. If the downlink data for LADN arrives frequently, the false paging occurs proportionally, which increases the UE power consumption and wastes the system resources.

B. Solution B: Location Reporting when Crossing the LADN boundary (LRCL)

In order for the network to be aware whether the UE is inside or outside of LADN service area, it is proposed that UE reports its location by performing the mobility registration procedure when it moves into or out of the LADN service area. With this solution, after the UE is informed of LADN service area during the registration procedure, it reports its location whenever it crosses the LADN service area boundaries so that the network is aware that the UE is located inside or outside of LADN service area.

The advantage of this solution is the network does not have to page the UE when the downlink data comes to the UPF in case that the UE is out of the LADN service area in CM-IDLE state since the network always knows whether the UE is inside or outside of the LADN service area.

The disadvantage of this solution is that the UE must report its location whenever it crosses the LADN service area boundary. It requires additional UE power consumption and uses the network resources to perform the registration update procedure. If the UE moves frequently in and out of the LADN service area, it does cost much.

V. Simulation Setup

A. User Walk Model

In order to reflect the human mobility patterns, we use the levy walk model proposed in [6]. In the levy walk model, a step is represented by four variables: fligh length (l), direction (θ), flight time (Δt_f), and pause time (Δt_p). The simulation interates the steps for the pre-defined simulation time.

In the walk model, flight lengths and pause times follow Levy distributions with coefficients α (set from 1.0 to 2.0, we use 1.5 as a default value) and β (set to 0.5 for all our simulations), respectively. We use an uniform flight direction distribution. We use the same speed model used in the Section IV of [6] to generate flight time. We dropped the randomly generated flight length if it is greater than the half of the length of the simulation plane. We also dropped the pause time if it is greater than 1,000 seconds. We also implemented the reflective movement when a simulation flight crosses a boundary of the simulation plane.

B. Registration Area and LADN service area

We use a similar structure of tracking area and registration described in [7]. Since the minimal granularity of the LADN service area is a tracking area, we don't take into account cell level network layout in our simulations. One tracking area represented in hexagon is assumed to have 600 meter for the inter-tracking area distance and each registration area consists of 9 tracking areas. We set the periodic registration timer (i.e. T3412) to the default value (i.e. 54 minutes) in [8].

Figure 3 shows how the registration area is constructed with multiple tracking areas. It shows the registration area (in blue lines) that consists of nine tracking areas (in black lines). It also shows how the simulation counts the mobility registration updates and the periodic registration updates as the UE moves. The UE starts the series of movements from the initial position marked in red circle. UE moves to the east and rotates 45 degree, moves to the northeast and rotates 45 degree and moves to the north to the final position marked in yellow circle.

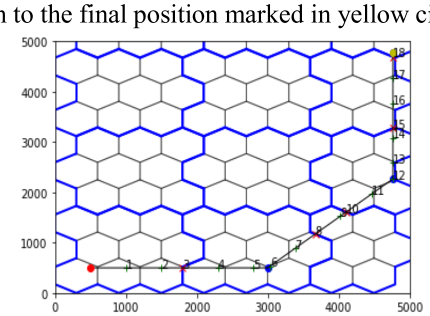

Fig. 3. Counting mobility and periodic registration update

To count the mobility registration updates, for every path of each movement, we check the registration area of each point. If we found the change of the registration area, we count another mobility registration update in that point. For an example, you can see those mobility registration update's points marked as green crosses in Fig. 3.

We also count the periodic registration updates for every movement and pause. For each movement, we compare the current simulation time and the elapsed time after the last registration update, we record the position of periodic registration updates performed on the path. For every pause period, we check how long it takes at the position after last registration update and count another periodic registration update if the periodic registration timer (set to 54 minutes) expires. For an example, you can see those periodic registration update's points marked as green crosses in Fig. 3.

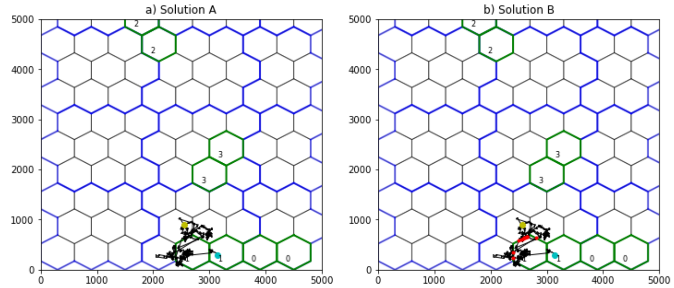

Fig. 4. Comparison of mobility registration updates

In our simulations, we randomly generate the LADN service areas. Throughout all simulations in this paper, we use the two tracking areas per one LADN service area. We use the LADN density (d) which denotes the LADN service area out of the simulation plane as a simulation parameter with default value set to 0.2.

As an example shown in the Fig. 4, we use the 10 percent LADN density and two TAs per one LADN service area (marked as green lines) as parameters and compared solution A and B by counting the registration updates. When we locate the starting position within the LADN service area, we found that are significant differences in the number of registration procedure.

In Fig. 4, the red points are the positions where the UE performs the registration update for solution B. In contrast, solution A does not require the UE to perform the registration update, (see that there is no red point in the Fig. 4a.) since the UE moves within the same registration area. In this example, solution A requires only 26 periodic registration updates, while solution B requires 11 mobility registration updates and 24 periodic registration updates during 24 hours of simulations time.

C. Downlink data arrival model and CM state duration

We use the Poisson arrival model for the downlink data with arrival rate (λ) as a simulation parameter with default value set to one downlink data arrival per hour.

We also assume that the UE is in CM-IDLE state for 90 percent of time based on the internal report about the smart phone usage model.

VI. SIMULATION RESULTS AND ANALYSIS

For performance comparison, we analyze two approaches in terms of the number of registration updates and the number of the false paging occurrences. With solution A, the number of false paging occurrences increases when the downlink data arrival increases while the number of registration updates is kept as the same. With solution B, the number of registration updates increases when the UE moves frequently across the LADN service area boundaries while no false paging occurs.

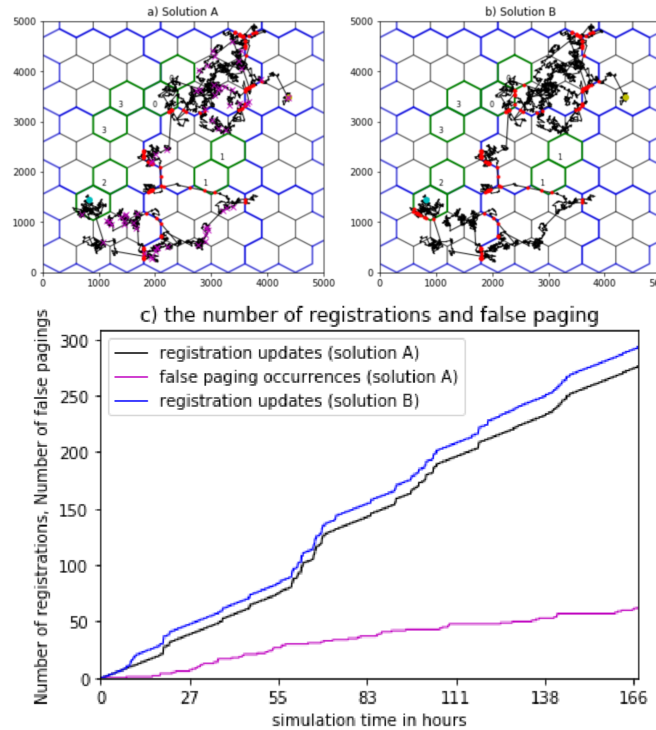

Fig. 5. The registration updates and false paging occurrences

Figure 5 shows one simulation result for solution A and B for 168 hours with an example configuration where LADN density (d) is set to 10 percent, user mobility parameter (α) is set to 1.5 with the same user mobility track, and downlink data arrival rate (λ) set to 1.0.

In Fig. 5a and 5b, we show the mobility registration updates in red points and the false paging occurrences in purple crosses on the same trajectory of one user. In Fig 5a, for solution A, the UE does not perform the registration update when it crosses the LADN service area within the one registration area. In contrast, in Fig 5b for solution B, the red points appears on those points (see the red dots in the bottom left side of LADN service area 2). In Fig. 5a, the purple crosses are the positions when the false paging occurs for solution A while there is no purple crosses in Fig 5b.

In Fig 5c, the black and purple lines shows the number of registrations and false paging occurrences respectively for solution A while the blue line shows the number of registration updates for solution B. The total number of registration updates of solution A is 276 (the number of mobility registration updates is 115 and the number of periodic registration updates is 161) with 62 false paging occurrences in purple line. The total number of registration updates for solution B is 293 (the number of mobility registration updates is 135 and the number of periodic registration updates is 158) with LADN availability 10 percent, which means that the UE spends 17 hours within the LADN service area out of total 168 simulation hours.

To compare two solutions in terms of UE power consumption, we discuss the number of additional operations caused by the each solution. For the solution A, we can consider additional operation caused by the solution A is the number of false paging since the UE must perform registration updates even without solution A. For the solution B, we can consider additional operation caused by the solution B is the differences of the number of registration updates between the solution A and B (i.e. the number of registration update for solution B minus the number of registration update for solution A). As shown in the Fig 5c for an example configuration, the additional operation caused by the solution A is the number of false paging occurrence (i.e. 62) and the additional operation caused by the solution B is the differences of the number registration updates (i.e. 293 – 276 = 17). In other words, the number of additional operations caused by the solution B is much smaller than that caused by solution A is. Since it is expected that the energy consumption required for the false paging is much higher than that required for the registration update, we can consider the solution B is much more energy efficient solution than the solution A is for this example configuration.

We run simulations for solution A and B one hundred times per each set of simulation parameters. Figure 6 shows the simulation results based on a) using different mobility parameters (α = 1.0 to 2.0) b) using different downlink arrival rates (λ = 0.5 to 2.0) and c) using different LADN densities (d = 0.1 to 0.6). Each simulation runs for 168 hours i.e. 7 days of simulation time.

For all cases, the number of registration updates of solution B is five to twenty percentage larger than that of solution A is. As shown in Fig. 6a, the high user mobility causes larger number of registration updates, which results in more power consumption of the UE. If we assume that no downlink data is coming to the UE, the solution A is much better in terms of UE power consumption. However, the downlink arrival rate is directly related to the number of false paging occurrences as shown in the Fig. 6b. In other words, if there is more than one downlink data per hour (λ=1) comes to the UE, the number of false paging occurrence is significantly larger, the solution B is much better. Interestingly, the LADN density, however, does not affect much on the number of registration updates. In other words, the number of the registration updates slowly increases as the density increases for solution B as shown in the Fig. 6c. The higher LADN density has the lower number of false paging occurrences.

As a summary of discussions, the performance of solutions in terms of UE power consumption is highly dependent on the arrival pattern of downlink data traffic. It is obvious that the solution A is better if no downlink data for the LADN. However, the performance of the solution A degrades significantly when the arrival rate of downlink data grows. Currently the data traffic pattern for LADN service is not known at this stage, the solution B also should be considered as one of options that operators choose when designing LADN for 5G System.

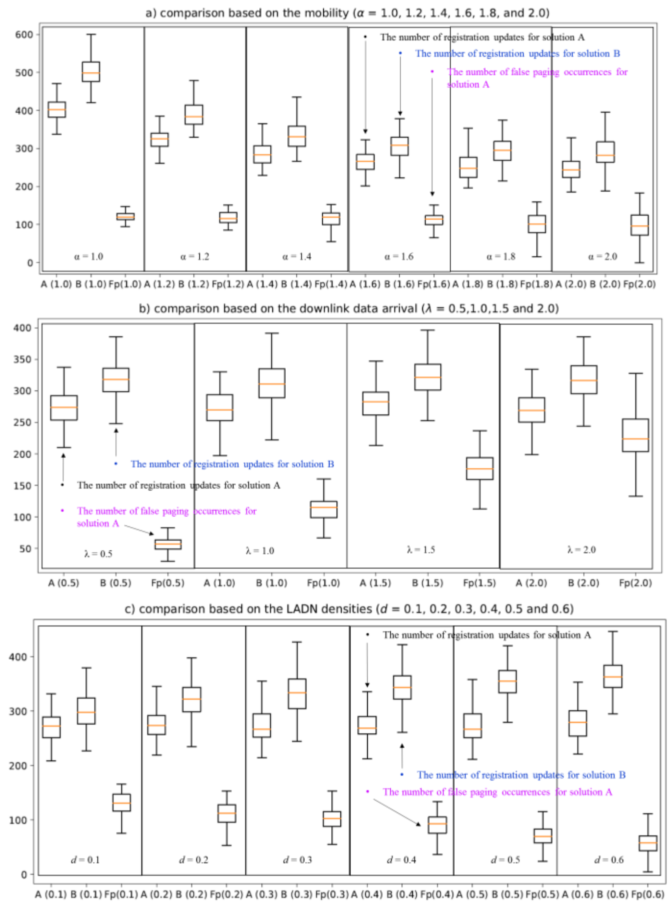

Fig. 6. Comparison of solution A and B with a) varying mobility, b) varying downlink data arrival and c) varying LADN density; Fp indicates the number of false paging occurrences in solution A.

VII. Conclusions

In this paper, we introduce a noble concept of Local Area Data Network for 5G System Architecture so that the operator launches 5G applications with low latency and high data rate requirements.

We describe the LADN operations of the 5G System to realize the proposed concept by defining the configuration and discovery of the availability of the LADN. We discuss two solutions for handling PDU session and compare the advantage and the disadvantage. To finalize the detailed design of the LADN solutions, we analyze two solutions in terms of the number of registration updates and the number of false paging occurrences. We conclude solution A is better in terms of the UE power consumption assuming that there are few downlink data arrivals. However, the solution B should be also an option for standardization that operators can choose.

Acknowledgment

We thank Stefano Faccin from Qualcomm who provided insights and contributions for LADN standardization in 3GPP SA WG2. We also thank Takeshi Usui from KDDI who drove an interim agreement on the support of LADN in 5G System Architecture.

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