論 文 の 内 容 の 要 旨

論文題目 Adaptive Architecture and Traffic Control for Metro-Access Network
(適応的メトロアクセスネットワークの構成とトラヒック制御に関する研究)

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In centralized radio access network (C-RAN) architecture, the base station (BS) functions are divided between a baseband unit (BBU) and remote radio heads (RRHs). The C-RAN architecture for Long Term Evolution (LTE) enables BSs to be deployed flexibly and cost-effectively. The increase in mobile traffic requires a higher increased wireless transmission rate and a larger number of small cells must be deployed. The network between the BBUs and the RRHs is called mobile fronthaul. A significant issue for the mobile fronthaul is the strict latency requirements. Furthermore, additional mobile network features that have effects on the fronthaul data transmission such as time-division duplex (TDD) and coordinated multipoint (CoMP) are discussed for 5G networks. In TDD systems, uplink and downlink transmissions occur based on time synchronization between neighboring RRHs. For telecommunication network carriers, efficiently locating BSs to satisfy ever increasing traffic demand has been a significant problem. Although a BS can be an evolved nodeB (eNB) or an RRH in the C-RAN, in this paper the word BS is used for simplicity. Conventional network architectures and BS location methods have considered dealing with spontaneous maximum traffic requests in the planning region. However, the timewise and spatial distribution of local traffic reflects the movement and fluctuation of demand distribution caused by moving hot spots or daily movement of users in the metropolitan-scale. In addition, the efficiency of network infrastructure will be deteriorated in shrinking cities of industrialized countries.

To address this problem, this paper proposed an adaptive metro-access network architecture. The goal of the proposal is to efficiently accommodate fluctuating traffic demand. The proposed network consists of metro networks and access

networks. It is a fixed-mobile converged network; traffic for various services are forwarded, e.g. mobile fronthaul/backhaul, residential services such as Internet traffic, and Internet of things (IoT) services such as sensors.

The access network consists of optical networks between a central office and BSs, subscribers' premises, and gateways for IoT devices. To efficiently satisfy the demand fluctuation in the metropolitan-scale, this paper proposes a novel concept of moving mobile network architecture. In the proposed architecture, dynamic BSs are deployed with a novel autonomous base station with optical reflex backhaul (ABSORB) architecture to efficiently satisfy the demand fluctuation in the metropolitan-scale. With the ABSORB architecture, the uplink and downlink traffic of demand nodes is forwarded to and from an autonomous BS connected to a gateway via flexible optical networks. ABSs autonomously move to new places according to a relocation schedule periodically rescheduled by a controller. The advantages of the ABSORB architecture are its low cost, high throughput, and versatility. The number of BSs are drastically reduced compared with conventional models that consider momentary maximum traffic requests using static BSs. The optical links can forward far more traffic than wireless backhaul links used in past architectures. The ABSORB architecture can be employed in various networks because it is independent of the RATs and optical transmission protocols.

Considering the limited and unstable bandwidth with existing wireless backhaul technologies for moving hot spots, the novel concept of optically backhauled moving network (OBMN) architecture is proposed to efficiently provide backhaul links for moving hot spots in local trains. In the OBMN, an ABS which is connected to a gateway via optical backhaul is set on the top of a train. It is a specialized architecture for local trains; optical fibers are laid along overhead lines without interruptions. While the train moves, the ABS always forward traffic of moving demand onboard through high-bandwidth optical backhaul link. To follow the movement of the train, the length of optical fiber is adequately adjusted with a high-speed reel located along the railway. To satisfy demand with the minimum number of ABSs, we proposed the ABS scheduling scheme which determines the position and state of each ABS based on train timetables. The OBMN can efficiently provide high and stable bandwidth using small number of BSs, unlike existing moving cell architectures with wireless backhaul.

This paper also introduces the usage of PON to efficiently deploy access networks for mobile fronthaul. To this end, it clarifies the application range of PON-based fronthaul architecture, which is expected to reduce the deployment cost of

fronthaul by sharing the optical fibers. This is because the optical link utilization and application range of PON-based architecture has not been quantitatively evaluated at system level. The optimization of optical transmission contributes to the reduction of the fronthaul deployment cost. Small cells can be efficiently accommodated either optical network topology on the basis of the application range, using the estimated number of users and data rates.

In addition, this paper proposes a novel DWBA algorithm for TWDM-PON with mobile fronthaul traffic with the consideration for TDD synchronization timing error. It addresses the high burstiness of fronthaul traffic received at ONUs because of the variable data rate generated by the functional split and the global synchronization of data transmission with TDD. The proposed scheme minimizes the number of active wavelength channels by considering the data reception timing and propagation delay between the OLT and ONUs. The PON-based mobile fronthaul can be efficiently configured with the proposed DWBA with the minimum number of active wavelength channels, and consequently the deployment cost is minimized.

Furthermore, it is a significant problem to quickly recover telecommunication services in the disaster-stricken area for improving the resilience of the optical access networks in the proposed architecture. To address this issue, this paper proposes a wired and wireless network cooperation (NeCo) system. The communication for dead nodes, whose wired connection is disrupted, is recovered by wireless bypass routes to active nodes. The bypass routes are determined to maximize the expected total PHY level wireless link throughput. The advantages are promptness and high-throughput, which is achieved with single-hop wireless bypass routes backhauled by optical networks. In addition, this paper introduces a planning scheme to optimally deploy recovery nodes in the NeCo system. With the proposed scheme, the number and location of recovery nodes can be optimized considering the relationship between the improvement of throughput and cost.

In the metro section of the proposed adaptive network, the QoS requirements for various services, e.g. mobile fronthaul/backhaul, residential services, and IoT services, are satisfied as the following. Mobile fronthaul is treated as the express class because of the strict latency requirements. Other services are forwarded as non-express traffic. The metro networks can be composed of layer-2 ring or switched fabric networks. For fronthaul transmission, the low-latency routing and scheduling schemes are proposed. The proposed schemes optimize the forwarding path for each fronthaul stream and queue scheduling for each fronthaul bridge based on the estimation of end-to-end (e2e) delay for each fronthaul stream.

With the proposed schemes, the increase in queuing delay caused by the TDD system is reduced and many radio equipments are efficiently accommodated in a bridged network.

Throughput fairness for non-express traffic is achieved with the previously proposed NRN+1CM. NRN+1CM can be employed for both ring aggregation networks and switched fabrics. With NRN+1CM, colors are assigned to frames based on the input rate, and frames are discarded based on their color coupled with a frame-dropping threshold. Through a threshold-notification process, NRN+1CM discards frames at upstream nodes, avoiding the accumulation of a queuing delay. In this paper it is proved that bufferbloat avoidance is achieved along with throughput fairness with NRN+1CM using the M(n)/M/1/K queue model. The state probabilities and average size of each queue were calculated with the proposed model, and the numerical results and simulation confirmed the validity of it.

Considering the urban shrinkage in industrialized countries, it is efficient to execute the node integration process in low-demand areas, where a node is integrated with another node and the integrated node is closed. It reduces the total operating cost to reduce the maintenance of open nodes by accommodating widely distributed subscribers to fewer number of nodes. This node integration process is an important component of the proposed adaptive network architecture. The dynamic node integration problem (DNIP) was proposed to organize the optimal plan for node integration. The problem of the DNIP was that it cannot consider the requirements of network carriers. In actual situations, network carriers often want to specify the way each node is managed, regardless of the mathematical optimality of the solution. To address this problem, this paper proposes a requirement modeling language (RML) for the DNIP, with which the requirements of network carriers can be described. The requirements of network carriers can be described in the optimization problems with the RML. If the described statements are used to solve the DNIP, the calculated solution always satisfies the requirements. The validity of the proposed method was evaluated with computer simulations, demonstrating that the optimal solution always satisfies the requirements.

This paper proposed an adaptive metro-access network to efficiently accommodate fluctuating traffic demand. The conceptual network architecture and traffic control schemes are introduced. The remaining challenges are the implementation and field experiment for the proposed architecture.