Optimum Baseband Resource Switching Interval Determination Method in C-RAN

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***Abstract*—The cloud radio access network (C-RAN) has become a promising architecture for future wireless communication system. In general C-RAN architecture, baseband units processing resource are centralized to form the baseband resource pool, which connects to remote radio units (RRUs) with the switching unit. In accordance with the traffic variation, the necessary on-state baseband resources are allocated to the RRUs in demand through the switching operation. This feature makes the system power variation accord with the traffic variation, which can reduce the unnecessary energy cost and save operating expense for mobile network operators. In practical implementation, switching intervals exist between adjacent switching operations. Shorter switching intervals bring the power variation closer to the traffic variation. However, frequent switching also brings about more overhead. Unlike simply setting the switching into a fixed value as in the literature, this paper proposes a method for calculating the optimum switching interval for the best cost saving effect for a given traffic pattern. Moreover, a fast calculating method is proposed for easy implementation.**

***Keywords*—C-RAN; Baseband; Resource sharing; Switching interval;**

I. INTRODUCTION

In the current Radio Access Network (RAN) in wireless communication system, the distributed base station (BS) architecture is becoming more and more popular. In the conventional all-in-one macro base station architecture, the analog, digital and power function devices are integrated in one large cabinet that needs dedicated deployment environment. The improvement of the distributed base station is that the radio function devices and the digital function devices are separated. In this architecture, the radio function devices form the remote radio unit (RRU), and the digital function devices form the baseband unit (BBU). One BBU connects to several RRUs with the fiber using a certain standard, such as Common Public Radio Interface (CPRI). The fiber is up to several kilometers long, which greatly increases the flexibility of base station deployment.

Based on the distributed architecture, the baseband resource pool scheme was recently introduced in the proposal of C-RAN from the China Mobile Research Institute (CMRI) [1]. Fig.1 shows the basic architecture of this scheme. Baseband processing resources are combined together as a pool or cluster. On the premise that the total number of RRUs is the same, unlike the separated BBUs scheme, the baseband resource pool scheme can change the on-state baseband processing resources in accord with the total traffic variation, which can reduce the baseband power consumption of the base stations. As the dense deployment for soaring mobile traffic has become popular in recent years, the ratio of micro cell, pico cell and even femto cell rises in the whole RAN. As discussed by Auer et al. [2], the power consumption of the baseband processing part occupies around 40% of the whole BS power. As a result, reducing the power consumption of the baseband part shows great importance in the whole system.

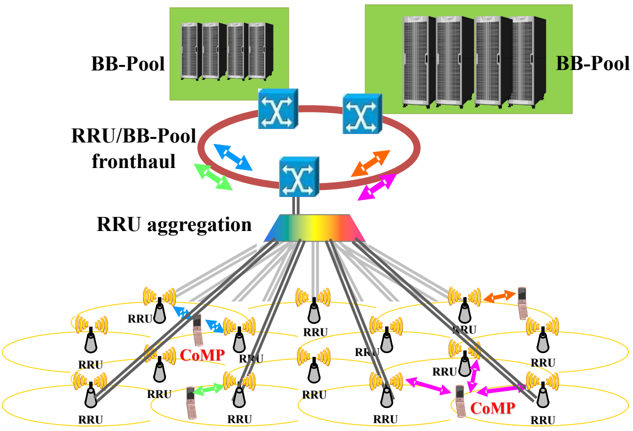

Fig. 1. Architecture of the baseband resource pool in C-RAN

In the C-RAN architecture, through changing the switch mapping in the switching unit (SU) and controlling the on-off state of the baseband resources, only necessary baseband resource are allocated for processing. This can avoid total baseband resources working at full load all the time and save power consumption. Ideally, the power variation can fit the traffic variation. However, switching intervals (SIs) exist between adjacent switching operations in practical implementation. Shorter SI would bring the power variation closer to the traffic variation and improve the power saving effect. On the other hand, switching operation needs the inherent overhead. Shorter SI would increases the switching operation times and brings about more overhead. In other words, there is a trade-off between the saving and the overhead in setting the SI. The optimum SI is the value that can achieve the best balance in the trade-off.

In the previous literatures [1][3], SI is simply set to fixed value such as one hour. However, the optimum SI is not always one hour for different traffic patterns. Unlike simply setting the SI to a fixed value, this paper proposes a method for calculating the SI for optimum cost saving effect for a given traffic pattern. Moreover, a fast calculating method is proposed for easy implementation.

The rest of this paper is organized as follows. Section II discusses the SI's influence on the power saving effect and the overhead from switching. Section III gives the process of calculating the optimum SI and the fast calculation scheme for easy implementation. Lastly Section IV draws the conclusion.

II. INFLUENCE ON POWER SAVING AND OVERHEAD FOR DIFFERENT SWITCHING INTERVALS

A. *Switching interval in C-RAN system*

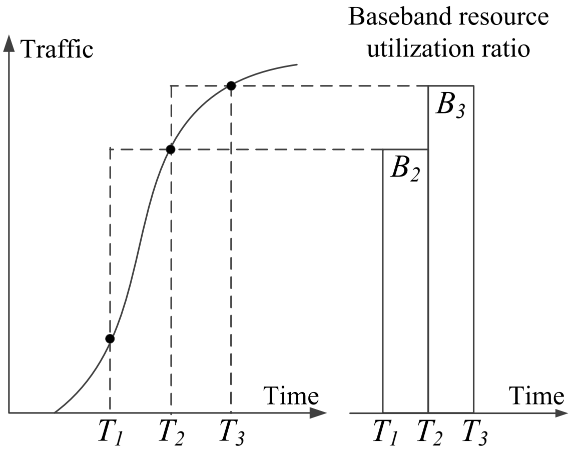

Fig. 2. Power saving effect of different switching interval

In the operation of C-RAN, the system controller must periodically predict the traffic in the next period of time and make the controlling strategy. For example, we know the mobile network traffic shows the diurnal character in everyday traffic [1][4]. Thus, the system controller can predict the traffic of the next day at midnight. Given the traffic prediction, the SI is an important parameter in making the controlling strategy. As shown in Fig.2, since interval exist between the switching operations and baseband resource allocation operations, we should allocate B_2 baseband resources at time T_1 in order to cover all the processing requirements between T_1 and T_2. This feature determines that the variation of the baseband resource utilization ratio is always the histogram approximation of the traffic variation. Since the power consumption of baseband resources is directly related to the baseband resource utilization ratio, the width of the histogram, i.e. the switching interval, is the most important parameter.

B. *Shorter switching interval saves more power*

In previous literatures such as Namba et al.'s work [3], the investigation resolution for the traffic and the corresponding SI is usually set to one hour. Although the analysis in hour units reveals the diurnal character of the traffic, the power saving effect has not been well studied. Fig. 3 shows the power saving difference between large and small SIs.

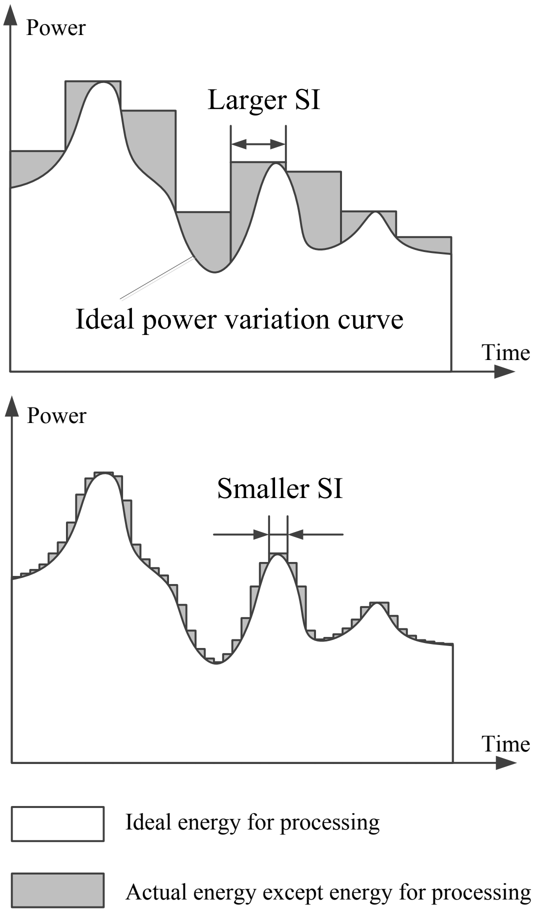

Fig. 3. Power saving effect of different SIs

As shown in Fig.3, assuming the baseband power achieves maximum value at the peak traffic, and the ideal power variation curve is exactly in accord with the traffic variation curve, the area in white shows the energy that is used for baseband processing in an ideal situation. During the SIs, the actual power during the SI should be the maximum value of this period. Thus, the actual energy is as shown in the gray area besides the processing energy. Obviously, the larger SI case consumes more energy than the smaller SI case.

To investigate the power reduction effect in changing the switching interval, two traffic variation patterns are studied. Fig. 4 shows the traffic variation pattern for the office area scenario from the CMRI [1]. Since the traffic resolution in this scenario [1] is in hour units, the data for higher resolution are obtained from interpolation. The whole day has four peaks, which come at the time before work starts, lunch time, afternoon break hour, and dinner time. Fig. 5 shows typical traffic variation of one train station area. This pattern is derived from the number of people in the station from a 2012 traffic census report [5]. In the morning, the traffic surges as the commuting hour approaching and achieves the maximum value from 7:00 to 9:00. In the evening peak period, the commute is not concentrated into the two hours, so the traffic peak is not as high as the morning peak, but lasts longer. The other important characteristic is that there are periodical small peak in the off-peak hours since the trains run every few minutes.

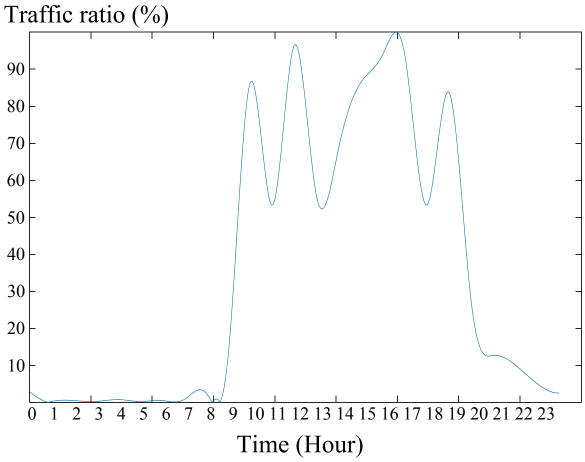

Fig. 4. Traffic variation for the office area scenario

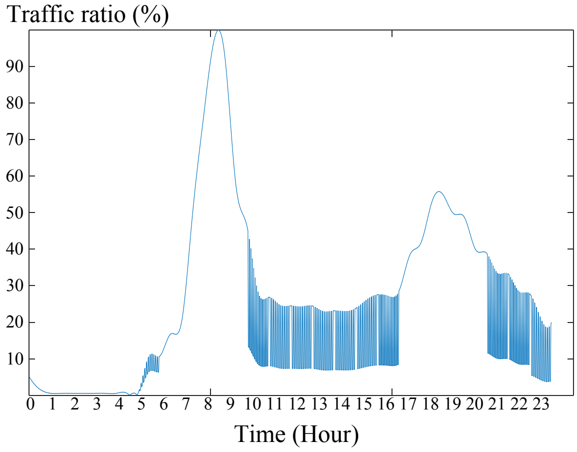

Fig. 5. Traffic variation for the station area scenario

Based on the two traffic variation patterns, if we change the switching interval from one hour to one second, the power reduction ratio in the ideal condition is as shown in Fig. 6.

As shown in Fig. 6, as the switching interval reduces, the total energy cost reduces. If we take all the devices working at full load all the time to be 100%, the energy cost with a one-hour SI is about 35% and 44% for the two patterns, while the ratio reduce to 23% and 35% with a one-second SI. Thus, there is sufficient space for tuning the SI to a shorter length for a better power saving effect.

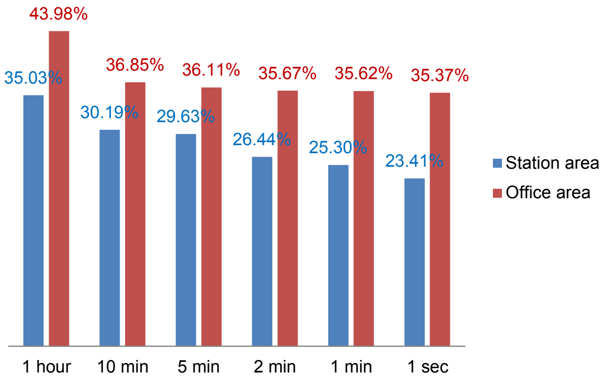

Fig. 6. Energy ratio of setting SI to different length

C. The overhead from switching

On the other hand, a shorter SI is not necessarily a better SI. For each switching operation, there is the switching time for completing the state changing of the hardware and software. During the switching time, since the system is working in transition state, it should give extra resource for completing the switching, which is regarded as the overhead of the switching. During the switching time, before the new assignment starts to work, a series of procedures should be carried out. For example, the corresponding baseband resource should be woken up or shut off, the system software should complete the communication with the on-line or off-line baseband resources, the computation data to be processed should be prepared and the switch unit should complete the data flow changing operation. All the operations should be completed in the switching time. Since the switching time is mainly determined by the hardware and system software design of the whole system, it can be regarded as a independent variable with the traffic. In other words, the overhead is related to the switching times. As the SI becomes small, the overhead increases as the switching times increases. Thus, this factor means that the SI cannot be set to too small.

To summarize this section, we find reducing the SI can improve the power saving effect but also bring about more overhead. The next section will discuss how to obtain the best trade-off and calculate the optimum SI value.

III. SWITCHING INTERVAL WITH THE BEST COST SAVING EFFECT

A. Best cost saving effect

Two relationships are considered in order to evaluate the trade-off of the cost saving effect. The first is between the saved cost by changing the SI and the SI value. As shown in Fig. 7, when the SI changes from T_{total} to T_{int}, the area in grid shows the saved cost brought about by the SI changing. As the SI becomes small, the actual power variation approaches the traffic variation and the saved cost approaches some fixed value for a certain given traffic pattern, which is shown as the solid line in Fig. 8. The upper bound means that the processing

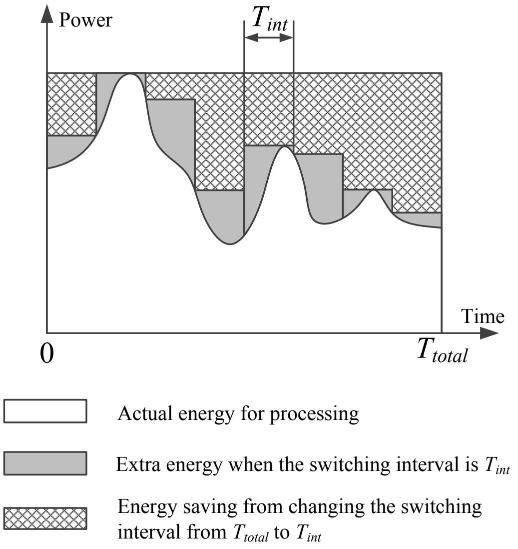

Fig. 7. Cost saving for reducing the switching interval

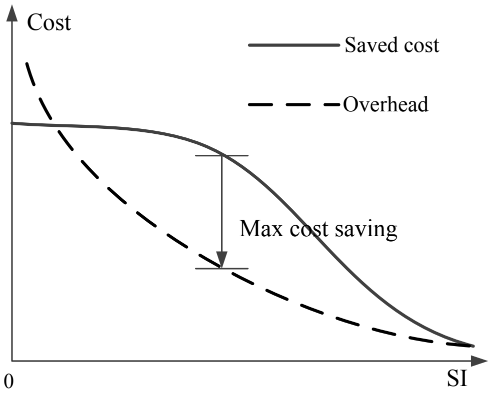

Fig. 8. Maximum cost saving point for different SI

power exactly accords with the traffic variation. The overhead shown in Fig. 8 as the dashed line also increases as the SI decreases, and the growing rate also increases. The left-hand limit means that when the SI reaches the switching time, the system always works at the transition state and all processing power is wasted. Thus, as (1), the target is to find the SI value that can bring about the maximum difference between the saving cost and the overhead.

$$\underset{T_{int}}{\operatorname{argmax}}\{C_{saved} - C_{overhead}\} \tag{1}$$

B. Fast switching interval calculation method

In practical implementation, the system controller predicts a traffic pattern based on the basis of the traffic history and other factors. The simplest way to calculate the optimum SI is traversing the possible value, calculating the saving cost and overhead and selecting the best value. However, since the brute-force search involves plenty of multiplications and additions in calculating the saving cost and overhead, this is a quite complex process that is not suitable for implementation. Consequently, a fast SI calculation method is considered for easy implementation.

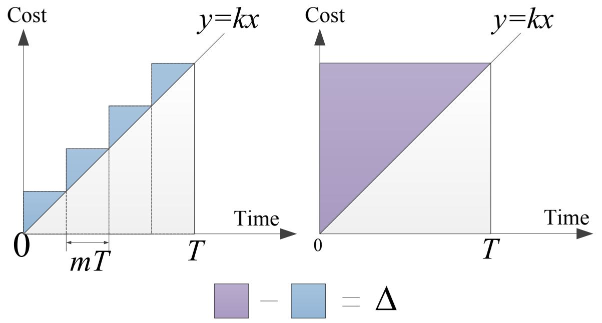

Fig. 9. Saving cost in the linear case

The basic idea of the fast calculation method is linear approximation. Fig. 9 shows the in the linear case, when SI decreases from T to $mT(m<1)$, the saving cost is as shown in (2).

$$\Delta = \frac{1}{2}T^2 k(1-m) \tag{2}$$

Take the linear approximation to the power variation curve shown in Fig. 10, wherein the whole curve is divided into n segments. The saving cost can be calculated as

$$\begin{aligned} C_{saved} &= \Delta_{01} + \Delta_{12} + \cdots + \Delta_{n-1n} \\ &= \frac{1}{2}(\frac{T_{total}}{n})^2(1-m)(|k_{01}| + \cdots + |k_{n-1n}|) \\ &= \frac{1}{2}(\frac{T_{total}}{n})^2(1-m)(|\frac{P_1 - P_0}{T_1 - T_0}| + \cdots + |\frac{P_n - P_{n-1}}{T_n - T_{n-1}}|) \\ &= \frac{1}{2}(\frac{T_{total}}{n})(1-m)(|P_1 - P_0| + \cdots + |P_n - P_{n-1}|) \end{aligned}$$

Note that

$$T_{int} = \frac{mT_{total}}{n} \tag{3}$$

Denote $\lambda = |P_1 - P_0| + \cdots + |P_n - P_{n-1}|$, the saved cost is represented as (4).

$$C_{saved} = \frac{1}{2}\frac{T_{total}}{n}\lambda - \frac{1}{2}T_{int}\lambda \tag{4}$$

On the other hand, since the overhead is independent from the traffic variation, it can be regarded as a function of the switching times as in (5), where the parameter η is the cost of each switching.

$$C_{overhead} = \eta\frac{T_{total}}{T_{int}} \tag{5}$$

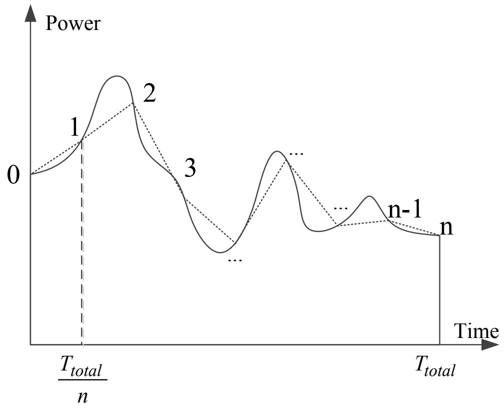

Fig. 10. Linear approximation for the whole traffic

Then the optimum SI in (1) is obtained by solving (6).

$$\underset{T_{int}}{\text{argmax}}\{\frac{1}{2}\frac{T_{total}}{n}\lambda - \frac{1}{2}T_{int}\lambda - \eta\frac{T_{total}}{T_{int}}\} \qquad (6)$$

Through differential equation, the solution of (6) is (7).

$$T_{int}^{opt} = \sqrt{\frac{2\eta T_{total}}{\lambda}} \qquad (7)$$

Therefore, the fast calculation method only needs to calculate the λ, and the final optimum SI can be computed by one step in (7). In calculating the λ, we should select the number n, which is the number of segments for the linear approximation. As the n increases, so the linear approximation accuracy also increases, the result of the fast calculation method would converge to the optimum SI value. According to the definition of λ, the total computation of the fast calculation method involves only several additions and subtractions, 2 multiplications, 1 division and 1 square root. Compared with the plenty of multiplication and additions in the brute-force search, the computation complexity is greatly reduce in the fast calculation method.

C. Experiment result

The simulation experiment in Matlab is carried out for two traffic patterns shown in Fig.4 and Fig.5. The traffic variation data in the simulation are the traffic ratio compared with the full load traffic at every second of one day. The brute-force search is setting the SI from one second to 24 hours, calculating the saved cost and overhead, and selecting the optimum SI at the maximum cost saving point. The fast approximation method is setting the number of segments n from 1, increasing the n with step length of 1, and calculating a series of SIs with (7). When the series of SIs reaches convergence, the optimum SI is obtained. The criteria for the convergence is that five consecutive items do not exceed 0.1% of the previous item.

Table 1 compares the SI setting to one hour and the SI setting to the optimum SI. The table lists the cost ratios compared with the case of working at full load all the time. With the optimum SI, cost saving effects are 8% and 11% more than when SI is fixed one hour.

TABLE I
COMPARISON RESULTS FOR THE ONE-HOUR SI AND OPTIMUM SI

SI	Cost ratio of office area	Cost ratio of station area
One hour	43.98%	35.03%
Optimum SI	35.53%	24.07%

To compare the fast calculation method and the brute-force search method, Table 2 and Table 3 shows the simulation results for the two traffic patterns. The final power saving effects of the two methods are very close. The fast approximation method achieves over 1000X speed-up in both traffic patterns.

TABLE II
COMPARISON RESULTS FOR THE OFFICE TRAFFIC PATTERN

Method	T_{int}^{opt}	Cost ratio	Computation time
Brute-force search	64s	35.53%	20.75s
Fast approximation method	64s(63.7s)	35.53%	0.006s

TABLE III
COMPARISON RESULTS FOR THE STATION TRAFFIC PATTERN

Method	T_{int}^{opt}	Cost ratio	Computation time
Brute-force search	17s	24.00%	21.20s
Fast approximation method	19s(19.4s)	24.07%	0.017s

IV. CONCLUSION

This paper discusses the optimum switching interval calculation method for C-RAN architecture. For different switching intervals, both the power saving effect and overhead brought about by switching are considered. The optimum switching interval achieves the best trade-off between the saving cost and the overhead. A fast calculating method is proposed for easy hardware implementation, which also shows great speed-up in the simulation. The discussion in this paper is based on the assumption that the traffic pattern is given. In actual operation, the traffic pattern would changes due to many factors. The adjusting scheme that can adjust the SI as the traffic pattern change will be considered as future work.

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