Efficient Paging Control for Carrier Aggregation in LTE-A System

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***Abstract*—This paper studies paging operation when carrier aggregation (CA) is adopted in LTE-A system. A numerical analysis is provided and shows signaling overhead would increase significantly if paging is not properly controlled under CA. To overcome the problem, efficient paging controls are proposed while adaptive paging configurations on different component carrier are able to resist excessive overhead. In additional, a hierarchical paging message delivery scheme is jointly controlled to take paging latency into account. The results demonstrate that our proposal can work well in different environments with minimum changes in 3GPP specification.**

***Keywords* — LTE-A, Carrier Aggregation, Paging, Signaling overhead**

I. INTRODUCTION

The fourth generation (4G) cellular wireless system, released by IMT-Advanced [1], continuously improves transmission rates to meet various requirements. Employing a wider spectrum is a straightforward way to increase the transmission rate, unfortunately, there may have a shortage of contiguous spectrum when deployed. Instead, the concept of using spectrum aggregation could be a feasible solution. Long Term Evolution-Advanced (LTE-A) system, specified by 3rd Generation Partnership Project (3GPP), considers carrier aggregation (CA) feature by aggregating two or more component carriers (CC) on different spectrum for supporting wide-spectrum operation [2], [3], in which an Evolved Node B (eNB) may utilize separate FFT and RF modules for different CCs and could use only one Radio Resource Control (RRC) layer to support CA functionalities. Based on user equipment (UE)'s capabilities and data requirements, eNB may serve each UE to operate at one or more CCs.

The serving CCs for the UE could be further categorized into Primary component carrier (PCC) and Secondary component carrier (SCC). PCC which provides most of control signaling will be unique for a UE and be changed only during a handover procedure. Oppositely, UE could operate on multiple SCCs which could be activated and deactivated by eNB's scheduling to support scalable bandwidth. From eNB's perspective, each CC shall have full capabilities and provide adequate system information to serve as an PCC for any incoming UEs. In addition, depending on operator's deployment, CCs from same eNB may have respective coverage and antenna configurations.

In cellular network, a terminal allows to turn off its transceiver power to save power and mitigate network loading when user does not have data transmission. In LTE-A system, a UE could go to idle state for the same purpose. During idle state, UE usually has two tasks: (1) cell reselection and (2) paging operation. Cell reselection is executed autonomously to select an appropriate eNB during UE's migration. Once a new target eNB is selected, UE may re-establish connection with the eNB and make location registration. Paging operation is a pull-based mechanism for eNB to notify idle UE when there is a call or some urgent information should be updated. A UE is required to periodically monitor paging indications and further re-establish the connection if there is a request from eNB. Moreover, tracking area (TA) in which consisting several eNBs coverage is introduced and UE is only required to make location registration while crossing the boundary of current TA. With location registration, network is able to trace UE's trajectory and perform paging based on the information.

There are numerous investigations on paging and TA optimization to seek a tradeoff between signaling overhead and UE power consumption. New registration strategies were proposed in [4], [5] to reduce the amount of signaling overhead with taking QoS into account. Improvements on tracking area which assigning multiple TA to a UE were discussed in [6], [7]. An efficient location management which considering overlapped deployment of Femto cell and Macro cell was discussed in [8]. Unlike previous investigations, an eNB may support multiple CCs in LTE-A system and it is still not clear how to efficiently provide paging signaling among those CCs and this paper will introduce an efficient paging control while reducing signaling overhead at the same time.

The rest part of this paper is organized as follows: in Section II, we explain paging operations in LTE-A system and disclose problems when CA is

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supported. The overhead calculation will also be introduced for further evaluation. An efficient paging control is proposed in Section III. Section IV discusses the simulation model and will provide numerical analysis to verify the proposed mechanism. Finally, conclusion is drawn in Section V.

II. PAGING OPERATION IN LTE-A AND PROBLEMS FOR CA

In LTE-A system, a UE is requested to monitor Physical Downlink Control Channel (PDCCH) at a paging opportunity sub-frame for every paging cycle. Different UE may be configured with different paging cycle whose value could be 32/64/128/256 frames. There are three patterns for allocating paging opportunities in one frame and eNB would indicate UEs its selected pattern. Consequently, a formula which functioned with UE's identification could scramble UE to respective paging opportunity sub-frame. That scrambling can offload paging overhead to different sub-frames. In regarding paging opportunity, UE will monitor PDCCH to see whether a Paging Radio Network Temporary Identifier (P-RNTI) is appended. If P-RNTI is appended, UE will further decode a paging message which was transmitted in Physical Downlink Shared Channel (PDSCH). In the message, eNB would specify paging purpose and regarding UE identification list. If its identification is listed, the UE is requested to initiate a random access (RA) process for re-establishing connection and sending a paging response to the eNB.

On the other hand, UE would verify the tracking area identifier (TAI) when it reselects a new target eNB during idle state. An eNB will periodically broadcast TAI together with its system information. If TAI is different from the one that UE has registered, UE is required to make location registration for updating new located area. In general, tracking area is a geographical region which consisting multiple eNBs coverage and its associated UEs could stay in idle state when moving in the same TA. With the management of registration, core network could demarcate UE's location and request eNBs in registered TA to send paging messages.

According to above operations, total signaling overhead (byte/second) can be categorized into paging overhead (PO) and registration overhead (RO) as expressed in following equations:

$$\mathrm{PO} = \sum_{U}(\alpha \times N \times O_p) + O_s \times N / SI_{period} \quad (1)$$

$$\mathrm{RO} = \mathrm{U} \times \frac{TA_{area} - SAFE_{area}}{TA_{area}} \times \gamma \times O_u \quad (2)$$

$$\mathrm{ISD_{TA}} = 2 \times \sqrt{N \times \left(\frac{ISD_{eNB}}{2}\right)^2}, ISD_{SAFE} = ISD_{TA} - 2 \times UE_{speed} \quad (3)$$

U is UE amount in the tracking area. α is the call intensity factor (a probability that a UE would be paged per second, assume there is less than one page per second per UE). N is the number of eNB in a tracking area. O_p , O_s , O_u respectively represent required bytes of paging message, TAI message, registration message. SI_{period} is the transmission period of system information. TA_{area} is the region size of tracking area where we approximate it as a circle. Fig. 1 is an example of the approximation and calculation; $SAFE_{area}$ called safe area (also approximated as a circle) is a region size where UE is unable to cross the tracking area during one second. The Inter-Site Distance (ISD) of $SAFE_{area}$ as shown in (3) would be TA's ISD minus twice UE moving distance per second. γ is a variable that stands as a direction probability to move outside the region of TA. Although registration was dealt by a new TA and RO would be a function of how many in-coming UE amount from neighboring TAs, it is complex to consider neighborhood in the analysis. A simple verification provided in Appendix shows the in-coming and out-coming UE amount for a TA would be very close and RO can be translated as a function of how many out-coming UE amount in the TA. Since UE is assumed to uniformly distribute in the TA, therefore out-coming UE amount would be proportioned to a region size ratio, as expressed in equation (2). Through calculations, it observes that a larger size of TA could reduce RO. Oppositely, larger TA included more eNBs will increase the PO.

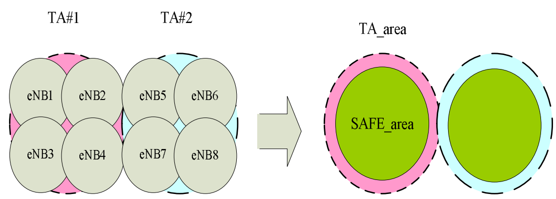

Fig. 1. Approximation of tracking area and safe area

Since each CCs being able to have different coverage and configure with different physical setting, UE might select one appropriate CC as its PCC based on its preference. Under this case, the eNB may not know which CC would be selected by a UE when UE stayed in idle state. As a result, all CCs should be involved for UE paging if eNB receives a request from core network. In this case, total signaling overhead (O'=PO+RO) would be:

$$\mathrm{O}' = \sum_{U}\{\alpha \times N \times K \times O_p + O_s \times N \times K / SI_{period} + U \times \frac{TA_{area} - SAFE_{area}}{TA_{area}} \times \gamma \times O_u\} \quad (4)$$

where we assume every eNB has identical CC amount in the TA and its size is K. The equation (4) obviously shows that PO will linearly increase with K value but no changes on RO.

An alternative case is let every CC be an individual tracking area within an eNB; as a result only one CC would perform paging based on the location registration. Under this implementation, total signaling overhead (O'') could be calculated as:

$$O'' = \sum_U \{\alpha \times N \times O_p + O_s \times N \times K/SI_{period} +$$

$$U \times [\frac{TA_{area} - SAFE_{area}}{TA_{area}} + (\frac{K-1}{K}) \times (\frac{eNB_{area} - SAFE_{area'}}{eNB_{area}}) \times \gamma \times O_u\} \quad (5)$$

$$ISD_{SAFE'} = ISD_{eNB} - 2 \times UE_{speed} \quad (6)$$

It could be found that PO in equation (5) does not change linearly with K, but RO will have additional cost. This is because UE needs to perform registration while crossing the eNB boundary and new CC has different TAI. No matter O' or O'', it shows signaling overhead would be increased when CA is supported and how to perform paging efficiently should need further study. In this paper, we propose an efficient paging control which targets to minimize signaling overhead while keeping the flexibility of CA deployment and usage.

III. PROPOSED PAGING CONTROL FOR CA

The proposed paging control comprises two steps: (A) adaptive paging configuration and (B) hierarchical paging message delivery. In step (A), three paging types are defined and an adaptive control is used to determine paging type on each CC. In step (B), an eNB will deliver paging message among CCs by a paging order. In the following, we elaborate the details for both steps:

A. Adaptive Paging Configuration

During paging, CCs could be configured into three types:

- Paging Unavailable (PU) CC: For that CC, no TAI is transmitted in system information. When selecting a PU CC as its PCC, UE would make registration and eNB may redirect the UE to other non-PU CCs.
- Paging Available (PA) CC: TAIs in the eNB are transmitted in the system information. When a UE selecting a PA CC as its PCC, UE might stay in idle state if one of TAIs is the same as its original registration. Otherwise, UE will make registration and network might assign one TAI to UE.
- Partial Paging Available (PPA) CC: An PPA CC only supports one TAI.

According to different TAI support, signaling overhead may be optimized by appropriately selecting the paging types. For example, PU CC is employed to save PO when a minority of UEs would be camped on the PU CC. Oppositely, if there are a lot of UEs with the same registered TAI camped on a CC, PPA CC would be the suitable paging type to save unnecessary RO. Moreover, as addressed in [9], network may require at least one CC to provide complete eNB's services coverage, thus that CC may be configured as PA CC since it has largest probability to serve UEs with respective TAI.

It could expect that paging configurations may depend on network deployment and UE's camping. Considering UE's camping would not be static, an adaptive control is proposed to configure CCs into appropriate paging types based on corresponding situation. Fig. 2 is proposed flow diagram for the adaption. AS shown, all CCs are initialized as PA CC. The eNB will examine amount of receiving responses at each CC every period of time. The response contains registration updates and paging responses. If response amount at a CC is below a pre-defined threshold (like T1 in Fig.2.), eNB will then configure that CC as PU CC. If the amount is larger than the threshold, eNB may further inspect what response are the most frequent case and compare the frequency ratio with another threshold, like X in Fig.2. (The ratio is defined as the response for a TAI divided by sum of responses for all TAIs). If the ratio is exceeding X, the CC would be configured as PPA CC to apply that most frequent TAI dedicatedly.

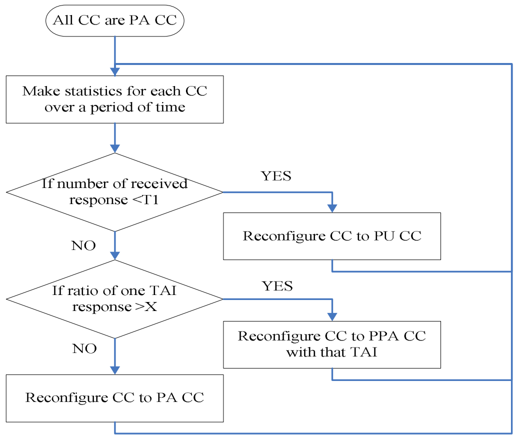

Fig. 2. Proposed adaptive control

With adaptation, regarding PO and RO would be changed as:

$$PO_{adap} = \sum_U \{\alpha \times N \times K(u) \times O_p +$$

$$O_s \times N \times (N_{PAA} \times 1 + N_{PA} \times K)/SI_{period}\} \quad (7)$$

$$K(u) =$$

$$\begin{Bmatrix} N_{\text{PPA with registated TAI}}, \text{when UE camped on PPA CC} \\ N_{\text{PPA with registated TAI}} + N_{\text{PA}}, \text{when UE camped on PA CC} \end{Bmatrix} \quad (8)$$

$$N_{PU} + N_{PPA} + N_{PA} = K \quad (9)$$

$$RO_{adap} = \{U \times \left[\frac{TA_{area} - SAFE_{area}}{TA_{area}} + \beta \times \frac{eNB_{area} - SAFE_{area'}}{eNB_{area}}\right]$$

$$\times \gamma \times O_u\}, N_{PU}/K \leq \beta \leq (K - N_{PA}/K\} \quad (10)$$

N_{PU},N_{PPA},N_{PA} is the number of CC configured as PU, PPA, and PA in an eNB and we assume identical configurations would apply to all eNBs in the tracking area. K(u) is the required CC amount to deliver paging message for UE u. The amount is determined by UE's camping and a paging order which would be discussed in step (B) in this section. $SAFE_{area'}$ is the safe region size in an eNB. β is a probability that UE would perform registration when camping on a new CC. The probability assembles two situations: (a) The new CC is a PU CC. (b) The new CC is a PPA UE with different TAI. Dependent on the number of paging type, the upper bound of β will be $(K-N_{PA})/K$ (no registration is required when selecting a PA CC) and the lower bound will be N_{PU}/K in case when all PPA CCs apply with identical TAI.

When introducing the adaption, additional statistics is required and increase the complexity. But from signaling overhead point of view, TAI is broadcasted periodically and the modification on TAI would not bring any updating signaling. As a result, no extra signaling needed be considered in the proposal.

B. Hierarchical Paging Message Delivery

Instead of sending paging message simultaneously, eNB is suggested to deliver paging message according to a hierarchical paging order. Following the order, eNB would perform paging and be terminated once receiving responses. Otherwise, eNB shall continue the paging until the end of order. With a proper order, it could save PO in which regarding overhead is only required at particular CCs. However, hierarchical paging may increase paging latency as compared with delivering paging message simultaneously at the first time.

To arrange paging order, according to LTE-A's specification, an eNB is allowed to repeat paging message no more than three times. Besides, it was comprehended delivering paging message at a PPA CC would have highest successful probability to receive UE's response with regarding to that TAI. Therefore, a suitable paging order is to deliver paging message at regarding PPA CCs in first time and involve all related CCs (PPA CC and PA CC) to deliver paging message during remaining two times when not receiving any response in the first time. With the order and assume UE could respond successfully after receiving the paging message, then $K(u)$ in (7) would be expressed by (8).

IV. NUMERICAL ANALYSIS

Table1 lists parameters adopted in LTE-A system and would be used in our numerical analysis.

TABLE 1. LTE-A system parameters

Parameter	Value
CC amount in an eNB (K)	5
UE amount in an eNB	200
Cell ISD	500 (m)
system information broadcast period	80 (ms)
O_p	6 (bytes)
O_s	2 (bytes)
O_u	176 (bytes)
A	0.05
γ	0.5
Averaged UE speed	3, 30 (km/hour)

Thereafter, four paging mechanisms are compared:

i) CCs are applied with identical TAIs.

ii) CCs are applied with respective TAI.

iii) Proposal without adaption (fixed one PA CC, three PPA CCs, and one PU CC).

iv) Proposal with adaption

Fig. 3 provides results when every CC has identical coverage and averaged UE speed is 3km/hr. It shows (ii) has smallest signaling overhead. This is because only one CC will perform paging in an eNB and registrations are not made frequently due to low speed. Oppositely, Fig 4 shows (i)'s signaling overhead is smallest when UE speed is 30km/hr. The reason is (i) uses universal TAI in an eNB and it would not have frequent registration under high UE speed. However, it is hard for network to predict UE mobility and provide appropriate paging control. Unlike (i) and (ii), both (iii) and (iv) reach a balance between PO and RO to accommodate the changes of averaged UE speed to avoid large signaling overhead variance. Furthermore, due to identical coverage, UEs may be uniformly camped on each CCs. Consequently, each CC has similar receiving response amount with respective to each TAI and let (iv) tries to configure all CCs as PA CCs. Therefore, (iv) will work better in 30km/hr but worse in 3km/hr as compared with (iii).

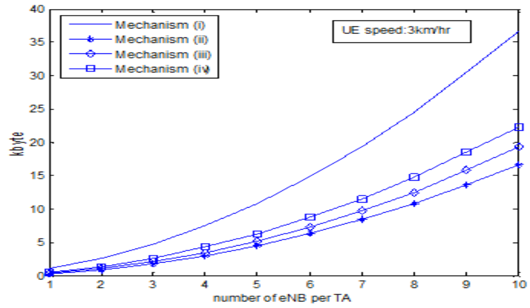

Fig. 3. Results under identical CC coverage and low UE speed

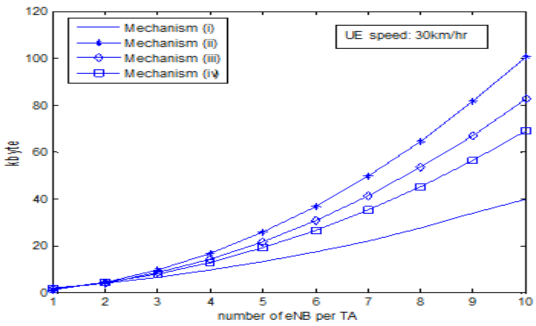

Fig. 4. Results under identical CC coverage and high UE speed

Alternatively, Fig. 5 (low averaged UE speed) and 6 (high averaged UE speed) are the results when CCs have different coverage in an eNB while three CCs only provide one third coverage of an eNB respectively, one CC provides full coverage of the eNB, and one CC whose ISD is half of eNB's. Results show that (i) and (ii)'s performance do not change so much under the deployment. On the other side, (iii) and (iv) have lower signaling overhead as compared with performance in identical CC coverage. In (iv), it especially could keep low signaling overhead in both low and high UE speed. This is because the adaption could figure out proper paging configurations among different CC coverage and then seek for lowest signaling overhead.

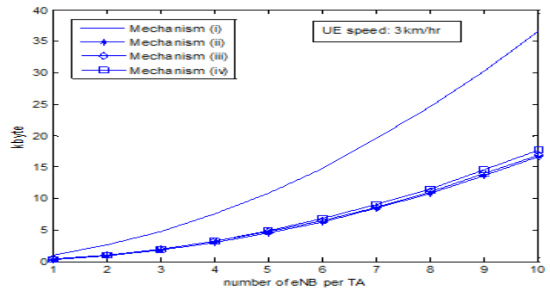

Fig. 5. Results under different CC coverage and low UE speed

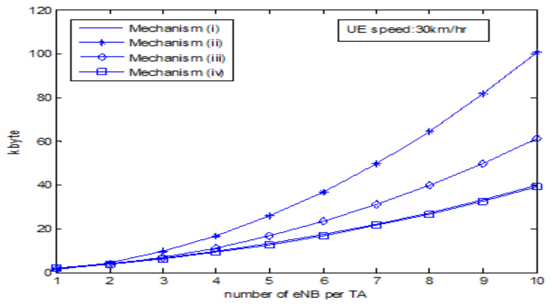

Fig. 6. Results under different CC coverage and high UE speed

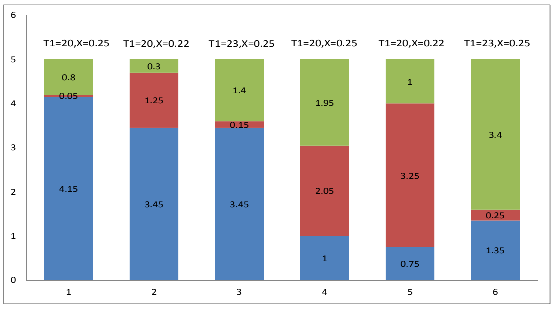

Fig. 7. Paging type for different thresholds in the proposal

When adapting, used parameters may influence the decisions and force different paging configurations. Fig. 7 is the composition of paging types by using different parameters (T1, X). The blue partition is the averaged PA CC number, red partition is PPA CC's, and green partition is PU CC's. It shows when X is smaller, PPA CC partition will increase; when T1 is larger, the PU CC partition will increase. For identical CC coverage (left three bars), Fig.7 also verifies most CC would be configured as PA CC and every CC would have different UE's camping ratio and paging configurations under different CC coverage (right three bars). From those results, our proposal is verified to be able to resist UE speed variation and outperform especial when CCs have different coverage.

V. CONCLUSION

In this paper, we investigate paging operations in LTE-A system and elaborate problems when CA is adopted. A numerical analysis is introduced to simplify the simulation. The analysis shows that without a proper control, signaling overhead would increase significantly. An efficient paging control considering three paging types with adaptive controls are designed to provide efficient paging operation. In additional, hierarchical paging message delivery scheme is jointly proposed to save the overhead. Our evaluation verifies that the proposal can not only accommodate different UE speed and CA deployment but also to resist the excessive overhead by adapting paging types among those CC. In the future, we will work on the paging order to make a better trade-off between overhead and latency for different paging purposes.

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APPENDIX

We want to prove in-coming UE amount is close to out-coming UE amount. The notation 'a' is used as ISD of TA and 'b' is used as UE speed (m/s). The ratio of out-coming and in-coming TA region is:$(a-b)/(a+b)$. Considering a>>b, therefore the ratio would be very close to 1. For example, when a=1000m, b=30 (km/hr) =8.33(m/s), then the ratio is 98.34%; when b=3 (km/hr) =0.833(m/s), the ratio is 99.83%.