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Directional-DRX for 5G wireless communications

M. Agiwal, M.K. Maheshwari, N. Saxena✉ and A. Roy

Directional-discontinuous reception (D-DRX) is proposed for millimetre-wave enabled fifth-generation communications. In addition to conventional active, short-sleep and long-sleep states, the proposed mechanism considers a separate beam searching state, to address alignment of directional beams between user equipment (UE) and evolved node B after a sleep cycle. Semi-Markov process is explored to capture various states of UE and probabilistically estimate its power saving and delay. A numerical analysis is conducted to validate the performance of D-DRX proposal. About 10% improvement is achieved in power saving with a marginal decrease in delay compared with maximum possible beam search time.

Introduction: Recently, third generation partnership project proposed tentative fifth-generation (5G) standardisation timeline with an initial focus on operation in high-frequency bands. Unlike sub-gigahertz frequencies, mmWaves need to overcome huge path-losses. Fortunately, small mmWave antenna arrays are capable of focusing narrow beams in the desired direction. Directional communication mitigates path-losses, reduces interference and improves spatial capabilities [1]. Multiple narrow beams at user equipment (UE) and evolved node B (eNB) would require many beams to be searched for efficient beam alignment [1]. At the same time, energy consumption at UE is likely to increase many fold driven by 5G enabled realistic ultra-high definition services, and the need for more power for variety of new applications. Computation expenses due to advanced 5G techniques such as space-division multiple access, high-order modulation, advanced coding, massive MIMO and so on further accentuate the need for energy saving at UE [1, 2].

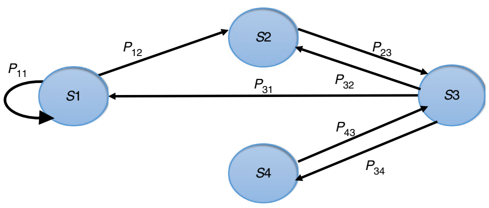

Fig. 1 *D-DRX states: Markov chain model for UE*

Discontinuous reception (DRX) plays a vital role in long-term evolution (LTE) and LTE-advanced (LTE-A) mobile technologies for power saving at UE. DRX enables UE to navigate from (an) active state(s) to short- and/or long-sleep cycle, leading to significant energy saving during sleep periods [3]. However, frequent beam misalignment in mmWave directional interface requires redesigning of DRX algorithm. Identification of best transmission–reception beam pair is crucial before UE wakes up and tries to receive data or control packet. This motivates us to propose a novel directional-DRX (D-DRX) mechanism by incorporating beam searching. Most of the previous works on DRX are focused on omni-directional networks. Though the work in [2] analyses DRX mechanism for analogue beamforming technique, beam search is incorporated in the sleep cycle itself. Moreover, the UE re-enters sleep on finding the best beam, making the beam pair obsolete at the time of actual communication. We believe that beam searching state, if designed independent of sleep mode, would provide higher degree of freedom to search algorithms. We perform a generalised DRX analysis by using four-state semi-Markov process as shown in Fig. 1 by considering a separate beam searching state. Semi-Markov is commonly employed for analysis of DRX process since times between state transitions are random. We also propose mechanism to reduce time spent by UE in beam searching state. Our proposal offers to establish communication between UE and eNB swiftly on beam alignment.

Directional-DRX: Fig. 1 shows the D-DRX mechanism, comprising of $S1$, $S2$ and $S4$ states representing active, only short-sleep and only long-sleep states respectively. State $S3$ represents beam alignment and a very short ON (active) period, to listen for any incoming data frames. If the inactivity timer of $S1$ expires before any new incoming packet, then the UE transits to the short-sleep state $S2$. Consequently after preset time, it makes a transition to $S3$, where it performs beam searching and subsequently checks for possible incoming data frames, on finding the best beam pair. UE transits to active state, if there is indication of new transmission, else it shifts to $S2$ again. If no new transmission occurs and the DRX short-cycle expires, then UE shifts to long-sleep cycle represented as $S4$. Shifting again to $S3$ is crucial after UE wakes up from long sleep for beam alignment. From $S3$ it either shifts to $S1$ or back to $S4$ depending on availability/unavailability of incoming data frames. For efficient D-DRX (i.e. high-power saving and reduced delay) the time UE spends in $S3$ must also be low.

In $S3$, UE measures the reference signal of different transmission beams (M beams indexed from $TX0$ to TXM) with each of the receiver beams (N) [2]. The beam pair for which the measured value becomes greater than the threshold is regarded as the best beam pair. The entire $M \times N$ sweeping takes a maximum of $BTmax$ time. However, the probability of finding the best beam pair might be earlier than $BTmax$. Thus, we propose dynamic adaptation of time in $S3$ ($T_{\rm bs}$) ranging to the maximum of $BTmax$ as shown in Fig. 2. The entire beam searching is performed in sections (subsets of $M \times N$). A feedback period is designated for UE to communicate to eNB, after UE beams sweep a section of transmitted beams. If there is no beam alignment, reference signals of the next set of beams are measured. Once the UE catches the best beam pair, a feedback is sent to eNB in designated feedback period as shown in Fig. 2. Channel reciprocity due to directionality enables eNB to swiftly send intimation of incoming data frames to UE on receiving the feedback.

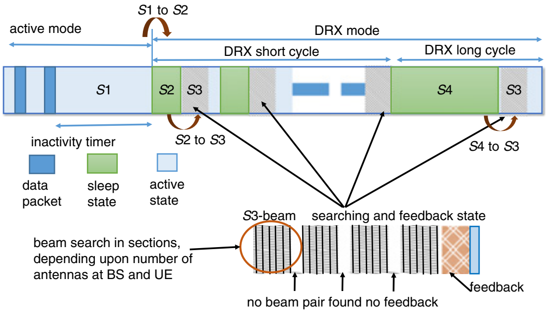

Fig. 2 *Beam alignment and feedback*

System model: We consider European Telecommunication Standards Institute (ETSI) traffic model for our analysis [4] and utilise main parameters $\lambda_{\rm ipc}$, $\lambda_{\rm is}$, N_p, $N_{\rm pc}$, $\bar{n}_p$ and $\bar{n}_{\rm pc}$ [2, 3]. According to an ETSI model, a new packet call may occur during the ongoing session or for a new session. Therefore, inter-arrival time between two packet calls maybe inter-packet call idle time ($t_{\rm ipc}$) with probability $p_{\rm pc} = 1 - 1/\bar{n}_{\rm pc}$ or inter-session idle time ($t_{\rm is}$) with probability $p_s = 1/\bar{n}_{\rm pc}$. If UE is in $S1$ and no packet arrives before inactivity time $t_{\rm I}$ expires, then UE transits from $S1$ to $S2$ with the probability p_{12}. However, on arrival of a new packet UE transits in the same state with the probability of p_{11} (Fig. 1). The probabilities are obtained as

$$p_{11} = P_{\rm pc}(1 - {\rm e}^{-\lambda_{\rm ipc}t_{\rm I}}) + P_s(1 - {\rm e}^{-\lambda_{\rm is}t_{\rm I}}) \tag{1}$$

$$p_{12} = P_{\rm pc}{\rm e}^{-\lambda_{\rm ipc}t_{\rm I}} + P_s{\rm e}^{-\lambda_{\rm is}t_{\rm I}} \tag{2}$$

Once short-sleep time $t_{\rm sc}$ expires, UE transits to $S3$ from $S2$ with state transition probability $P_{23} = 1$. In $S3$, after beam searching ($t_{\rm bs}$), if UE receives information of a new packet, it goes to $S1$ with probability p_{31}; otherwise, UE goes back to $S2$ with probability of p_{32}. After $N_{\rm sc}$ consecutive short cycles (along with corresponding beam searches), UE shifts to $S4$ (probability p_{34}). The state transition probabilities at $S3$ are expressed as

$$p_{31} = P_{\rm pc}(1 - {\rm e}^{-\lambda_{\rm ipc}t_{\rm bs}}) + P_s(1 - {\rm e}^{-\lambda_{\rm is}t_{\rm bs}}) \tag{3}$$

$$p_{32} = P_{\rm pc}{\rm e}^{-\lambda_{\rm ipc}t_{\rm bs}}(1 - {\rm e}^{-\lambda_{\rm ipc}N_{\rm sc}t_{\rm sc}}) + P_s{\rm e}^{-\lambda_{\rm is}t_{\rm bs}}(1 - {\rm e}^{-\lambda_{\rm is}N_{\rm sc}t_{\rm sc}}) \tag{4}$$

$$p_{34} = P_{\rm pc}{\rm e}^{-\lambda_{\rm ipc}t_{\rm bs}}({\rm e}^{-\lambda_{\rm ipc}N_{\rm sc}t_{\rm sc}}) + P_s{\rm e}^{-\lambda_{\rm is}t_{\rm bs}}({\rm e}^{-\lambda_{\rm is}N_{\rm sc}t_{\rm sc}}) \tag{5}$$

Similar to $S2$, the state transition probability of a transition from $S4$ to $S3$ is $p_{43} = 1$ (to enable beam searching). $\pi_i \, \forall i \in \{1, 2, 3, 4\}$ denotes the steady-state probability of staying at state Si. Using $\sum_{i=1}^{i=4} \pi_i = 1$ and balance equation $\pi_i = \sum_{i=1}^{i=4} \pi_j P_{j,k}$, stationary distribution can be evaluated. Next, we derive holding time $E[H_i]$ of semi-Markov process at state Si. The holding time for $S1$ is given as

$$E[H_1] = \frac{\overline{n}_p - 1}{\lambda_p} + \frac{P_{\mathrm{pc}}}{\lambda_{\mathrm{ipc}}}(1 - \mathrm{e}^{-\lambda_{\mathrm{ipc}} t_I}) + \frac{P_s}{\lambda_{\mathrm{is}}}(1 - \mathrm{e}^{-\lambda_{\mathrm{is}} t_I}) \tag{6}$$

The holding time for $S2$ is estimated as

$$E[H_2] = t_{\mathrm{sc}} \tag{7}$$

In $S3$ UE searches for beam for time t_{bs}, sends feedback to eNB and monitors the control channel. The mean holding time for $S3$ can be calculated as

$$E[H_3] = P_{\mathrm{pc}} \frac{(1 - \mathrm{e}^{-\lambda_{\mathrm{ipc}} t_{\mathrm{bs}}})}{\lambda_{\mathrm{ipc}}} + P_s \frac{(1 - \mathrm{e}^{-\lambda_{\mathrm{is}} t_{\mathrm{bs}}})}{\lambda_{\mathrm{is}}} \tag{8}$$

Similar to mean holding time of $S2$, the mean holding time for $S4$, with t_{lc} long-sleep time, is given by

$$E[H_4] = t_{\mathrm{lc}} \tag{9}$$

Using (6), (7), (8) and (9) power saving factor γ is computed as

$$\gamma = \frac{\pi_2 E[H_2] + \pi_4 E[H_4]}{\sum_{i=1}^{4} \pi_i E[H_i]} \tag{10}$$

However, this power saving is achieved at the expense of increase in delay, as the packets arrived during sleep time are buffered at eNB. The expected delay $E[D]$ due to DRX operation is given by

$$E[D] = PS_2 \delta_2 + PS_3 \delta_3 + PS_4 \delta_4 \tag{11}$$

where PS_2, PS_3 and PS_4 are probabilities of packet arrival and δ_2, δ_3 and δ_4 are the average delays during $S2$, $S3$ and $S4$, respectively. The values can computed as

$$\delta_2 = t_{\mathrm{sc}} - P_{\mathrm{pc}} \frac{(1 - \mathrm{e}^{-\lambda_{\mathrm{ipc}} t_{\mathrm{sc}}})}{\lambda_{\mathrm{ipc}}} - P_s \frac{(1 - \mathrm{e}^{-\lambda_{\mathrm{is}} t_{\mathrm{sc}}})}{\lambda_{\mathrm{is}}} \tag{12}$$

$$\delta_3 = (t_{\mathrm{bs}} - t_{\mathrm{on}}) - P_{\mathrm{pc}} \frac{(1 - \mathrm{e}^{-\lambda_{\mathrm{ipc}} (t_{\mathrm{bs}} - t_{\mathrm{on}})})}{\lambda_{\mathrm{ipc}}} - P_s \frac{(1 - \mathrm{e}^{-\lambda_{\mathrm{is}} (t_{\mathrm{bs}} - t_{\mathrm{on}})})}{\lambda_{\mathrm{is}}} \tag{13}$$

$$\delta_4 = t_{\mathrm{lc}} - P_{\mathrm{pc}} \frac{(1 - \mathrm{e}^{-\lambda_{\mathrm{ipc}} t_{\mathrm{lc}}})}{\lambda_{\mathrm{ipc}}} - P_s \frac{(1 - \mathrm{e}^{-\lambda_{\mathrm{is}} t_{\mathrm{lc}}})}{\lambda_{\mathrm{is}}} \tag{14}$$

Now, the probability of PS_2 can be computed as

$$PS_2 = \alpha_{\mathrm{pc}} \mathrm{e}^{-\lambda_{\mathrm{ipc}} t_{\mathrm{sc}}} \left(\frac{1 - \mathrm{e}^{-N_{\mathrm{sc}} \lambda_{\mathrm{ipc}} t_{\mathrm{sc}}}}{1 - \mathrm{e}^{-\lambda_{\mathrm{ipc}} t_{\mathrm{sc}}}} \right) + \alpha_s \mathrm{e}^{-\lambda_{\mathrm{is}} t_{\mathrm{sc}}} \left(\frac{1 - \mathrm{e}^{-N_{\mathrm{sc}} \lambda_{\mathrm{is}} t_{\mathrm{sc}}}}{1 - \mathrm{e}^{-\lambda_{\mathrm{is}} t_{\mathrm{sc}}}} \right) \tag{15}$$

where $\alpha_{\mathrm{pc}} = P_{\mathrm{pc}}(1 - \mathrm{e}^{-\lambda_{\mathrm{ipc}} t_{\mathrm{sc}}}) \mathrm{e}^{-\lambda_{\mathrm{ipc}}(t_I - t_{\mathrm{sc}})}$ and $\alpha_s = P_s(1 - \mathrm{e}^{-\lambda_{\mathrm{is}} t_{\mathrm{sc}}}) \mathrm{e}^{-\lambda_{\mathrm{is}}(t_I - t_{\mathrm{sc}})}$. Moreover, similarly PS_3 and PS_4 can be computed as

$$PS_3 = \beta_{\mathrm{pc}} \left(\frac{\mathrm{e}^{-\lambda_{\mathrm{ipc}}(t_{\mathrm{bs}} - t_{\mathrm{on}})}}{1 - \mathrm{e}^{-\lambda_{\mathrm{ipc}}(t_{\mathrm{bs}} - t_{\mathrm{on}})}} \right) + \beta_s \left(\frac{\mathrm{e}^{-\lambda_{\mathrm{is}}(t_{\mathrm{bs}} - t_{\mathrm{on}})}}{1 - \mathrm{e}^{-\lambda_{\mathrm{is}}(t_{\mathrm{bs}} - t_{\mathrm{on}})}} \right) \tag{16}$$

$$PS_4 = \gamma_{\mathrm{pc}} \left(\frac{\mathrm{e}^{-\lambda_{\mathrm{ipc}} t_{\mathrm{lc}}}}{1 - \mathrm{e}^{-\lambda_{\mathrm{ipc}} t_{\mathrm{lc}}}} \right) + \gamma_s \left(\frac{\mathrm{e}^{-\lambda_s t_{\mathrm{lc}}}}{1 - \mathrm{e}^{-\lambda_{\mathrm{is}} t_{\mathrm{lc}}}} \right) \tag{17}$$

where

$$\beta_{\mathrm{pc}} = \begin{cases} P_{\mathrm{pc}}(1 - \mathrm{e}^{-\lambda_{\mathrm{ipc}} t_{\mathrm{bs}}}) \mathrm{e}^{-\lambda_{\mathrm{ipc}}(t_I + t_{\mathrm{sc}} - t_{\mathrm{bs}} + t_{\mathrm{on}})} & \text{after } t_{\mathrm{tsc}} \\ P_{\mathrm{pc}}(1 - \mathrm{e}^{-\lambda_{\mathrm{ipc}} t_{\mathrm{bs}}}) \mathrm{e}^{-\lambda_{\mathrm{ipc}}(t_I + N_{\mathrm{sc}} t_{\mathrm{sc}} + t_{\mathrm{lc}} - t_{\mathrm{bs}} + t_{\mathrm{on}})} & \text{after } t_{\mathrm{lc}} \end{cases}$$

$$\beta_s = P_s(1 - \mathrm{e}^{-\lambda_{\mathrm{is}} t_{\mathrm{bs}}}) \mathrm{e}^{-\lambda_{\mathrm{is}}(t_I - t_{\mathrm{bs}} + t_{\mathrm{on}})}, \text{ and}$$

$$\gamma_{\mathrm{pc}} = P_{\mathrm{pc}}(1 - \mathrm{e}^{-\lambda_{\mathrm{ipc}} t_{\mathrm{lc}}}) \mathrm{e}^{-\lambda_{\mathrm{ipc}}(t_I + N_{\mathrm{sc}} t_{\mathrm{sc}} - t_{\mathrm{lc}})},$$

$$\gamma_s = P_s(1 - \mathrm{e}^{-\lambda_{\mathrm{is}} t_{\mathrm{lc}}}) \mathrm{e}^{-\lambda_{\mathrm{ipc}}(t_I + N_{\mathrm{sc}} t_{\mathrm{sc}} - t_{\mathrm{lc}})}.$$

Numerical results: For the D-DRX analysis, we considered three sectors at each eNB with 12 beams per sector. We assume six beams for the UE, thus UE must sweep a total 72 (12 × 6) beam pairs to select the best one. In our analysis, UE searches beams in sections (six beams per section) and then a feedback time is designated for communication to eNB. Considering 72 beam sweeps, 12 feedback periods (after 12 sections) and 10 ms frame size, the maximum beam search time adds up to $BT_{\max} = 840$ ms. Thus, the time UE spends in beam searching state varies from 120 to 840 ms, depending on the best beam pair matching. Fig. 3*a* shows the power saving in D-DRX against short-cycle duration, for different arrival rates λ, with $t_{\mathrm{lc}} = 10$ s. However, as duration of short cycles increases, the effect on power saving becomes less prominent due to delay in long-sleep cycle. Increase in short-sleep duration also increases the average delay as depicted in Fig. 3*b*. In Figs. 3*c* and *d*, the long-cycle duration is increased when $t_{\mathrm{sc}} = 2$ s. The trends are similar to variation of power saving and delay with long-cycle duration in legacy networks [3]. Thus, performance of D-DRX is analogous to LTE-DRX performance, emphasising the effectiveness of DRX in mmWave environment. Fig. 3*e* delineates power saving of the proposed D-DRX compared with the maximum beam searching time $\mathrm{BT}_{\max}$. D-DRX achieves almost 10% benefit in power saving compared with maximum beam search time ($\mathrm{BT}_{\max}$). At the same time, as shown in Fig. 3*f*, marginal decrease in delay is also obtained due to possibility of faster beam alignment.

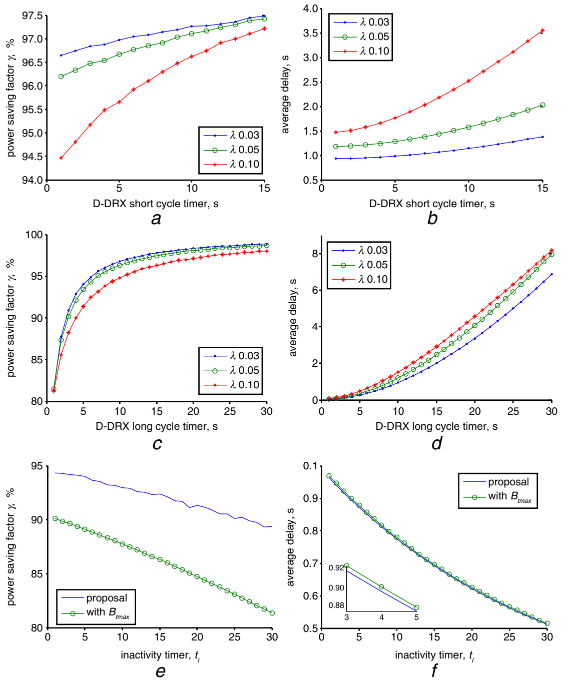

Fig. 3 *Numerical Analysis of D-DRX*

a Short-cycle power saving factor
b Short-cycle delay
c Long-cycle power saving factor
d Long-cycle delay
e D-DRX power saving compared with $\mathrm{BT}_{\max}$
f D-DRX delay compared with $\mathrm{BT}_{\max}$

Conclusion: In this Letter, we presented the D-DRX mechanism for mmWave enabled directional 5G environment. Our numerical analysis using semi-Markov model emphasises the importance of beam searching as a separate state in DRX mechanism. In D-DRX once the best beam pair is identified, a feedback by UE initiates a swift communication from eNB. Our proposed mechanism improves power saving by almost 10% compared with maximum beam search duration, with a marginal decrease in delay as well.

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One or more of the Figures in this Letter are available in colour online.

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References

1 Agiwal, M., Roy, A., and Saxena, N. : 'Next generation 5G wireless networks: a comprehensive survey', *IEEE Commun. Surv. Tutor.*, 2016, **18**, (3), pp. 1617–1655

2 Kwon, S.W., Hwang, J., Agiwal, A., *et al.*: 'Performance analysis of DRX mechanism considering analogue beamforming in millimeter-wave mobile broadband system'. IEEE Globecom Workshops, Austin, TX, December 2014, pp. 802–807

3 Fowler, S., Shahidullah, A.O., Osman, M., *et al.*: 'Analytical evaluation of extended DRX with additional active cycles for light traffic', *Comput. Netw.*, 2015, **77**, pp. 90–102

4 'Universal mobile telecommunications system (UMTS); selection procedures for the choice of radio transmission technologies of the UMTS', UMTS 30.03 TR 101 112 V3.2.0, April 1998