Bridging electrical power and entropy of ONU in EPON

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This letter deliberates bridging of overall electricity power requirements of the optical network unit (ONU) with the entropy noted through the ONU state transition models considered in ethernet passive optical network (EPON). The entropy depends on the steady state and transition probabilities of data. On the other hand, the power requirements (consumption) of ONUs depend on the steady sate probability of ONUs. The potential relation derived between the entropy and electrical power reveals that they related exponentially but for their logarithmic reliance. Also, the relation is validated through the numerical simulation. The deduced relation has its importance to understand the nuances of one entity given the other.

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In recent years, the awareness on energy efficiency and controlled consumption of power motivated the research attention towards passive optical network (PON). The optical line terminal (OLT) at central office assigns the bandwidth grant through the GATE message for upstream and downstream transmission as per the reported bandwidth in queues. However, the nuance of such data transmission is also hooked on electricity requirements for the active devices of optical network unit (ONU) and OLT. Thus, the subsystems of PON, such as OLT, ONU, and source of electricity supply have equally important role for effective data communication. In Asia-Pacific region, the installation of ethernet passive optical network (EPON), a standard of PON, is majorly observed. The EPON, which is an Ethernet frame-based technology, is analogous to well established local area network (LAN) technology.

In EPON, many methods discussed about the data transmission mechanisms with the energy efficient sleep and doze states for an ONU[1-5]. The entropy, an average information randomness of the data, in the literature, was discussed in the economic system management/estimation[6-11]. A few of the papers deliberated the integration mechanisms of PON with various electricity suppliers that highlighted the battery-powered ONUs and the connectivity of supply chains to different subsystems of PON[12-14]. In this work, for the first time, a potential relation is established to relate the entropy and the electrical power (required) noted through state transitions model of the ONU.

The schematic representation of the PON to derive the inter-relation between entropy and electrical power required is shown in Fig.1. The network consists of OLT, *N* number of ONUs, and splitter. Where, the OLT and ONU are active subsystems and the splitter is a passive intermediate system. This system classification is done based on the electrical power requirement of the subsystems to operate as shown in Fig.1. Moreover, the emergence of multimedia applications and internet of things(IoT) has provisioned the ONU to have its connectivity with various active systems. In the centralized control scheme, to avoid collisions, the OLT at central office controls the data traffic of ONUs in time division multiple access (TDMA) manner. Thus, each ONU consists of data transmission duration (active time) and waiting time (idle time). Also, the total active time durations of all ONUs in the network is known as cycle time. Moreover, during the stipulated active period of an ONU, both upstream and downstream transmissions occur simultaneously. The power conservation had been attempted in the literature[1,15-17] by considering either doze state or sleep state as idle state besides active state in the state transition model.

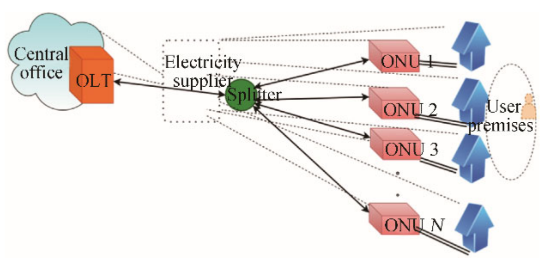

Fig.1 Basic PON architecture

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In the EPON, the OLT controls the time duration for various ONUs through the multi-point control protocol (MPCP) message, 'GATE' in a TDMA manner. Further, the polling sequence of the ONUs considered is fixed polling sequence with fixed (constant) cycle time for all cycles. To understand the pattern of power savings and to allocate the cycle times to meet the Quality of Service (QoS), a different set of ONU state models are considered as shown in Fig.2. Fig.2(a) represents the active doze model (AD model) with the states, active and doze while Fig.2(b) represents the active sleep model (AS model) with the states, active and sleep.

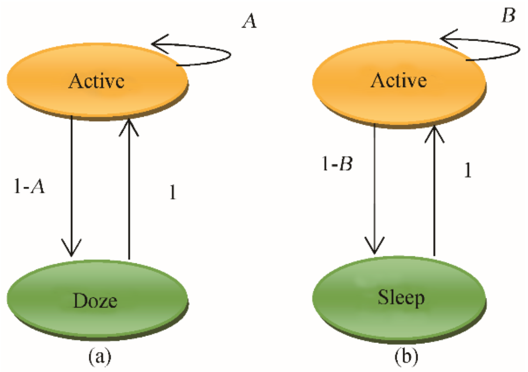

Fig.2 ONU State transition models: (a) AD model[1]; (b) AS model

Initially, the discrete time Markov chain (DTMC) state transition models for ONU as shown in Fig.2 are developed. In addition, this DTMC model follows memory less property. Also, it is presumed that the idle state represents either doze state or sleep state as per the model considered. These models epitomize that the ONU is, initially, at active state and transits to either idle state or active state depends on the arrival rate of packets (packets/ms) observed for that cycle time duration. Further, it is assumed that the ONUs considered are identical and have constant bit rate (CBR) traffic. The intra active state transition probability (A) for the AD model as in Fig.2(a)[1] and intra active state probability (B) for the AS model as in Fig.2(b) is represented in Eqs.(1) and (2), respectively. Where, the packet arrival rates in downstream and upstream are represented as λ_d and λ_u, respectively. The active steady state probability (u_1) and the steady state probability of doze or sleep state (u_2) are calculated from the intra-state transition probability observed as explained by the methodology given in Ref.[16].

$$A=1-\mathrm{e}^{-\lambda_u\times T_{\mathrm{cycle}}}\times\left(1-\mathrm{e}^{-\lambda_d\times T_{\mathrm{cycle}}}\right), \tag{1}$$

$$B=1-\mathrm{e}^{-(\lambda_u+\lambda_d)\times T_{\mathrm{cycle}}}. \tag{2}$$

As per the conditions stated above, the ONU can also be in an idle state with the steady state probability as mentioned above. However, the assigned fixed cycle time determines the idle time for the considered fixed polling sequence. They specify the actual scope for the probability of idle time as the arrival rate is limited but the assignment of fixed cycle time will result in loss of packets. Incidentally, if the steady state probability of idle state is zero or lesser than the threshold considered, the OLT enables one more wavelength channel to meet the traffic needs. Similarly, the number of ONUs operated per enabled wavelength channel also varies. This mechanism reduces the cycle time as in Eq.(3). Thus, the idle state probability increases. However, the wavelength channel enabling procedure in this work is processed by considering the transition probability from active state to idle state. That in turn institutes for idle steady state probability. The detailed description about the threshold is given in the inferences for the results. In Eq.(3), R_u is the upstream line rate for a single wavelength channel that increases with the number of enabled wavelength channels, and W_{max} is the bandwidth granted. Thus, the cycle time (T_{cycle}) for single enabled wavelength channel is represented as

$$T_{\mathrm{cycle}}=N\times\frac{W_{\max}}{R_u}. \tag{3}$$

Similarly, the power consumption of ONU (P_c) depends on steady state probability and power consumption of each state as represented in Eq.(4). P_{idle} represents the power consumption of idle state and P_{act} denotes the active state power consumption. P_{trans} is the additional power consumption that accounts the power requirement for the transition period. Then, the total power consumed by one ONU can be given by

$$P_c=u_1\times P_{\mathrm{act}}+u_2\times P_{\mathrm{idle}}+P_{\mathrm{trans}}. \tag{4}$$

The communication between the source of electricity and the ONU happens in terms of bits. According to state transition model considered and the traffic arrival rate, the change in the state of the ONU that is either active or idle state is conveyed to the suppliers as bit, '1' or '0', respectively. Therefore, with the variation in the bit observed, the state transition and steady state probabilities are determined. Further, the entropy(H) as discussed in Ref.[8] also depends on the steady state and state transition probabilities as denoted in Eq.(5)

$$H=-\left\{u_p\times\left[C\times\log C+\left(1-C\right)\times\log\left(1-C\right)\right]\right\}, \tag{5}$$

where C and $1-C$ represent the probability of getting '1' as a next bit given the present bit as '1'and the probability of getting '0' given the present bit as '1', respectively. Additionally, u_p represents the steady state probability of getting '1'. It is expected that the steady state probability of getting '1' is equivalent to the steady state probability of active state (u_1). Similarly, the probability 'C' is equivalent to the transition probability 'A'. Thus, from the Eqs.(4) and (5), it can be understood that the power consumption and entropy are related to the steady state probability.

The steady state probability, which is a common term for both entropy and power consumption, is ascertained based on the inter-arrival rate of packets between OLT and ONU. On the other hand, it is determined between ONU and electricity suppliers accounting the logic value (nature) of the bit, a reflectance of change in states. As mentioned above, the steady state probability of getting '1' can be represented in terms of power estimation and the power consumption at various states of the ONU as in Eq.(6). Here, it is presumed that the system established in this work can estimate the power consumption of the ONU, hence in Eq.(6), the estimated electrical power required by the ONU P_{est} replaces the power consumption of the ONU (P_c) while rearranging Eq.(4).

$$u_p = \frac{P_{est} - P_{trans} - P_{idle}}{P_{act} - P_{idle}}. \quad (6)$$

With the entropy (H), the electrical power required for the ONU (P_{est}) can be estimated through

$$P_{est} = P_{trans} + P_{idle} - \frac{H \times (P_{act} - P_{idle})}{\left[A \times \log A + (1-A) \times \log(1-A)\right]}. \quad (7)$$

Similarly, the state and transition probabilities can be computed for the model shown in Fig.2(b). Though using Eq.(6), it is possible to estimate the electrical power at the supplier premises, Eq.(7) has its scope to relate the inter-dependency between entropy and electrical power. Thus, through the established relational model, we can also deduce the information flow across the system.

The models established are simulated using MATLAB software to understand the insight of the relation. The power consumption of different states is computed with the condition that the state transition time is negligible[18]. The simulation parameters considered with their associated value are given in Tab.1. The traffic arrival process is assumed to be Poisson in nature. The simulation is carried out by varying both upstream and downstream traffic per ONU. Further, at given time, the upstream traffic is kept equal to downstream traffic. Initially, when ONU is at active state, it is observed that the variation in the arrival rate revealed an increased active state probability and decreased inter-state transition probability.

Tab.1 Parameters considered for simulation

No.	Parameter	Value
1.	Active state power consumption (P_{act})	3.985 W
2.	Sleep state power consumption	1.28 W
3.	Doze state power consumption	3.85 W
4.	Number of ONUs (N)	32
5.	Packet arrival rate per millisecond (λ_d)	1 200 to 4 000
6.	Cycle time variation (T_{cycle})	2 ms to 10 ms
7.	Upstream line rate (R_u)	10 Gbit/s
8.	Transition power consumption (P_{trans})	0.8 W

For the CBR traffic assumed at the ONU, we have considered different cycle times of the network and observed the response of the system with the suggested state transition models. It is to be noted that these considered cycle times are the initial cycle times with single enabled wavelength channel. The cycle time of the network also reveals the bandwidth granted to each ONU. Thus, with the small value of cycle time, the bandwidth granted is lesser and with the large value of cycle time, the bandwidth granted would be more. However, the considered small cycle time is allowing the ONU to transit to the idle state and the large value of cycle time is not allowing the ONU to transit to the idle state. Again, it is to be noted that the idle state of a particular ONU is the active duration for other ONUs. Hence, to maintain the same bandwidth grant and also to allow the ONU to be in idle state, the system will have to enable multiple wavelength channels. However, the pattern of wavelength channels enabling scheme is limited by a threshold for the transition probability, '1−A'.

As discussed above, to maintain the transition probability of the idle state at threshold (0.2 in this case), the cycle time is altered and the respective deviation in the entropy and the power consumption is plotted in Fig.3(a) for chosen AD model. Through the arrival rate considered and for the given cycle time of 10 ms, the power consumption of the ONU and the entropy are computed individually and their responses are plotted. The results suggest that the two entities are related exponentially. The nonlinear relation for the state model with idle states namely, doze and sleep is shown in Fig.3 (a) and (b), respectively. The response also reveals that the power consumed by the system through AD model is more than that of AS model. That is owing to the sleep state with its transceiver in *off* state rather than the transmitter only *off* as in the case of doze state. AD model exhibits almost linear relationship because of the less variation in the power consumption between doze and active states. However, the non linearity is evident in AS model due to large variation in the sleep and active states power consumption.

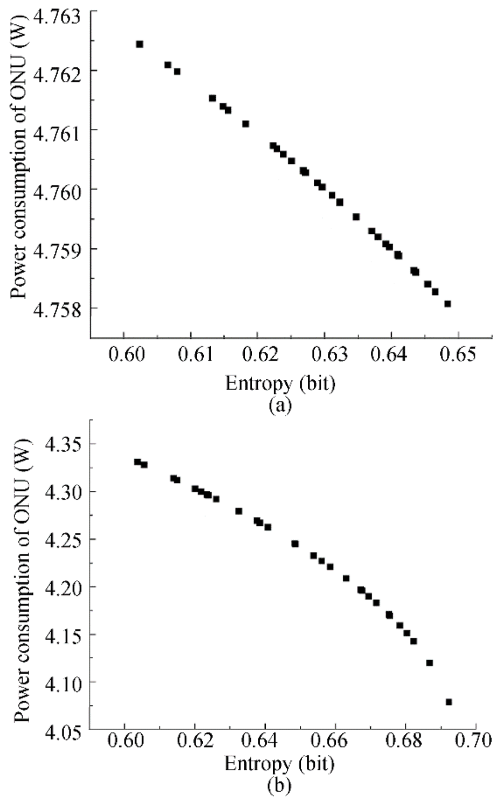

Fig.3 ONU power consumptionin fixed polling sequence with CBR traffic: (a) AD model and (b) AS model

The variation in the entropy by changing the packet arrival rate is illustrated in Fig.4. It reveals the effect of reduction in cycle time with number of enabled wavelength channels. For the chosen range of arrival rate, we can observe from Fig.4 that the network with initial cycle time of 10 ms has the same entropy with that of the network with the initial cycle time of 2.5 ms, which is obtained by enabling more wavelength channels. This is also possible for the rest of the cycle time cases. As the entropy is similar in both the situations, the former can be mapped to the latter. That is the range of arrival rate can be substituted by proper number of enabled wavelength channels. It is observed that the number of wavelengths required for maintaining the threshold is more in the case of AS model than AD model.

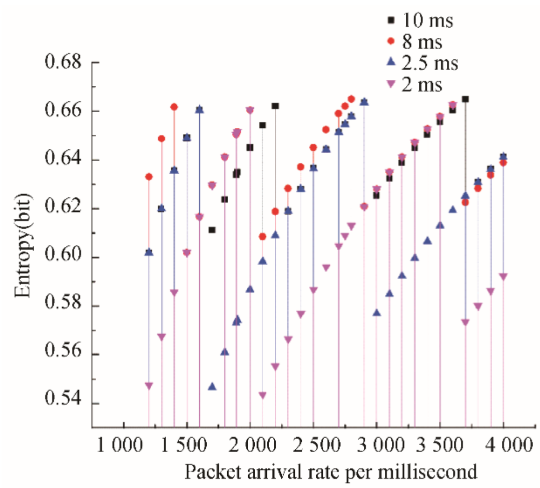

Fig.4 Trajectory of entropy variation with different initial cycle times in AS model

The condition with different cycle times could possibly attempted by forecasting[19] the arrival rates of the ONUs in various cycles. Then the average arrival rate of the ONUs within the cycle can be computed. Moreover, the initial (first) cycle time of the ONUs is assumed. The remaining cycles time duration is computed proportionately to the values of average arrival rate per cycle. Here the cycle time must be taken as the time required for one complete sequence of upstream access that is from ONU 1 to ONU N in a fixed polling sequence. However, the active time of all ONUs in the cycle is equal and is calculated as per the identified cycle time value. Then, the cumulative active time, idle time, and the observation period per ONU will vary. Accordingly, the average value ($T_{\rm cycleavg}$) of active time and idle time of all ONUs can be calculated. However, the challenge is to relate the average value of time durations and the wavelength allocation procedure. The modified equation to do the job is given in the Eq.(8). $T_{\rm cycleavg}$ and the average arrival rate is utilized for the computation of the transition probabilities as in Eqs.(1) and (2). In addition, the trajectory is assumed to be in the same pattern due to the similarity in the respective equations in both cases for the given conditions. While this different cycle time based approach is out of scope for this work. It might be considered as a future work.

$$T_{\rm cycleavg}=N\times\frac{W_{\rm max}}{R_{\rm u}}\times\frac{T_{\rm cycleavg}}{T_{\rm cycle}}\,. \tag{8}$$

The EPON, one of the much demanded access network technologies for realization of the next generation networks. In recent days, the researchers have concentrated in all spheres of this network by emphasizing and exploring its subsystems so as to achieve effective and efficient performances including power consumption. This manuscript brings out the relation existing between entropy of the PON with that of electrical power required for its normal functioning of sub systems like ONU. The derived potential relation for the chosen PON would reveal much insight about the functional attributes of the system for the given polling sequence. Further, between entropy and power consumption, if one of them is not known, through this relation, the other can be ascertained.

References

[1] A. A. Nikoukar, I. S. Hwang, Y. M. Su and A. T. Liem, Optical Fiber Technology **30**, 81 (2016).

[2] Y. Lv, N. Jiang, K. Qiu and C. Xue, Journal of Optical Communications and Networking **7**, 516 (2015).

[3] A. Dixit, B. Lannoo, G. Das, D. Colle, M. Pickavet and P. Demeester, Journal of Optical Communications and Networking **5**, 240 (2013).

[4] R. Bhargav Ram and R. Nakkeeran, Adaptive Scheduling Mechanism with Variable Bit Rate Traffic in EPON, Journal of Optical Communications, (2019).

[5] R. Bhargav Ram and R. Nakkeeran, Frontiers of Optoelectronics **12**, 422 (2019).

[6] Ji Wu, M. Li and C. Lee, IEEE/ACM Transactions on Audio, Speech, and Language Processing **23**, 2026 (2015).

[7] J. Yao and P. Venkitasubramaniam, IEEE Transactions on Smart Grid **6**, 2417 (2015).

[8] M. Nemani and F. N. Najm, IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems **15**, 588 (1996).

[9] P. Velarde-Alvarado, C. Vargas-Rosales, R. Martinez-Pelaez, H. Toral-Cruz and A. F. Martinez-Herrera, Telecommunication Systems **61**, 609 (2016).

[10] J. A. Rodger, Forecasting of Radio Frequency Identification Entropy Viscosity Parking and Forwarding Algorithm Flow Risks and Costs: Integrated Supply Chain Health Manufacturing System (ISCHMS) Approach, IEEE Journal of Radio Frequency Identification **1**, 267 (2018).

[11] W. Jiang and Y. Wang, IEEE Access **8**, 32432 (2020).

[12] H. Ujikawa, T. Yamada and N. Yoshimoto, Demonstration of Timer-Based ONU Deep Sleep for Emergency Communication During Power Failure, IEEE Global Communications Conference, (2013).

[13] Z. Sun, Y. Ma, F. Sun and Y. Wang, Access Control for Distribution Automation Using Ethernet Passive Opti-

cal Network, Asia-Pacific Power and Energy Engineering Conference, (2010).
[14] W. A. Imtiaz, Y. Khan, A. Qamar, J. Khan and N. A. Khan, Optoelectronics Letters **10**, 137 (2014).
[15] I. Hwang, A. Nikoukar, Y.-M. Su and A. T. Liem, Journal of Optical Communications and Networking **8**, 238 (2016).
[16] P. Sarigiannidis, M. Louta, G. Papadimitriou, M. Theologou, IET Networks **5**, 71 (2016).
[17] L. Shi, B. Mukherjee and S. S. Lee, IEEE Network **26**, 36 (2012).
[18] S.-W. Wong, L. Valcarenghi, S.-H. Yen, D. R. Campelo, S. Yamashita and L. Kazovsky, Sleep Mode for Energy Saving PONs: Advantages and Drawbacks, IEEE Globecom Workshops, (2009).
[19] N. E. Frigui, T. Lemlouma, S. Gosselin, B. Raider and R. L. Meur, Optimization of the Upstream Bandwidth Allocation in Passive Optical Networks Using Internet Users' Behavior Forecast, International Conference on Optical Network Design and Modeling, (2018).