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Energy Efficient Rate Adaptation Algorithm for FiWi Access Network

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***Abstract*— Similar to any telecommunication network, energy efficiency is a desirable feature for fiber wireless (FiWi) access networks. These networks have optical back end and wireless front end. Both ends may contribute for energy efficiency. This work focuses on front end of FiWi access network, which is IEEE 802.11a wireless local area network (WLAN). For energy saving WLAN uses power saving mode (PSM), in which sleeping opportunity of a station is increased. During sleep time, station remains switched off and results in reduction in energy required. However, it is also observed that during active period of transmission considerable energy is consumed, which is the function of rate of data transmission. More data rate results in more active energy consumption but less transmission delay and vice versa. In order to reduce active and hence total energy consumption, we tried to transmit the data at lower data rate, while maintaining transmission delay in tolerable limit. This paper presents an Energy Efficient Rate Adaptation Algorithm (EERAA) for the front end of fiber wireless access networks. Simulation results compare the energy efficiency and transmission delay of EERAA and various existing fixed data rate schemes. Proposed scheme offers good trade-off between energy efficiency and transmission delay.**

***Index Terms*—** Energy Saving, FiWi access network, PSM, Rate adaptation, WLAN, STA.

I. INTRODUCTION

FiWi access network is supposed to be best the candidature for next generation broadband access networks. It has ability to serve a large number of users with required quality of service. It provides high bandwidth and stability due to optical back end, while mobility and ubiquity due to wireless front end [1]. The generalized architecture of FiWi access network is shown in fig. 1.

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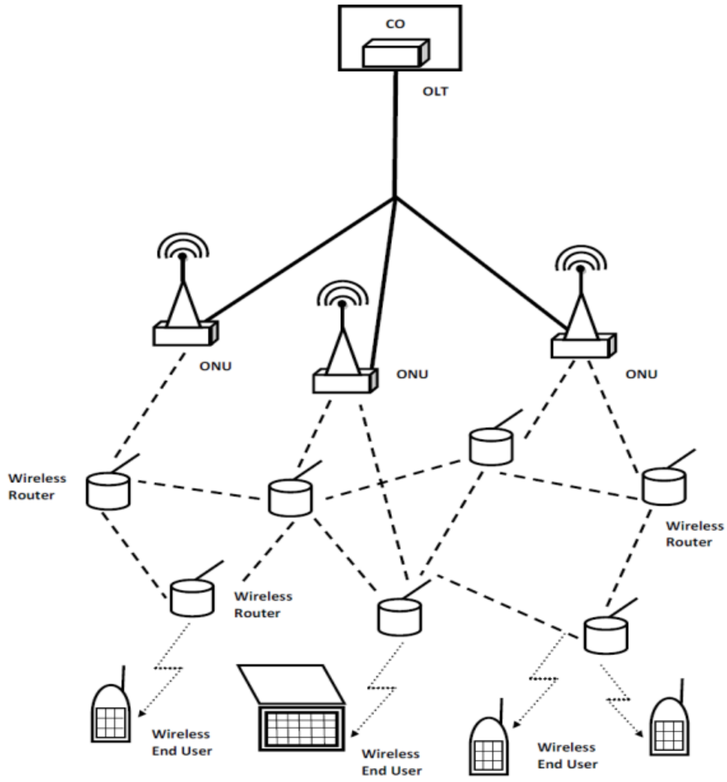

Fig. 1. Architecture of FiWi

FiWi access network is also known as wireless optical broadband access network (WOBAN).The back end sub-network is a passive optical network (PON). The optical line terminal (OLT) is the integral part of it which is directly connected to the core Internet and performs all the controlling functionalities, hence also referred as center office (CO). Various optical network units (ONUs) are connected with single OLT through an optical splitter. OLT to optical splitter link is referred as feeder fiber and splitter to ONU link is referred as distribution fiber. ONU is the interface between both the PON and wireless network. ONU performs the protocol translation for the sub-networks. In a FiWi access network the front end sub-network is a wireless access network. In this work, the IEEE standard 802.11a WLAN is considered as front end sub-network, where various routers or stations are connected to an access point [2].

Design of an energy efficient network is utmost requirement nowadays. FiWi access network also desires the energy efficiency [3]. There are different mechanisms available to achieve energy efficiency at front end and back end sub networks. In most of the energy saving approaches used for front and back end sub-networks, the device will turn off their transceiver either fully or partially in idle state [4]. Proposed work is focused on reduction in energy consumption of front end WLAN sub-network by rate adaptation algorithm along with power saving mode (PSM).

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II. RELATED WORK

Energy saving in optical back end is achieved by cyclic sleep mechanism. It consists of two states; active and sleep. In most of the researches sleep period of ONU is optimized for increasing the sleeping opportunities. ONU sleep refers to completely or partially turnoff of ONU when it is idle. Idle means it does not has any upstream or downstream data to send or receive. Generally sleep period for ONU is controlled by OLT. There may be three types of sleeping mechanisms- dozing, deep and cyclic sleep [5]. In dozing sleep mode the transmitter is turned off for sleep period but receiver remains in awaken state. In a deep sleep mode all the transceiver components are turned off for entire sleep period results in maximal power saving. Deeply slept ONU can wake up only when customer turns it on. It is preferably used when traffic loss due to sleeping is tolerable. In a cyclic sleep mode both transmitter and receiver get turned off periodically and sleep period is decided according to traffic arrival pattern [5].

For wireless sub-network the power saving mode (PSM) is usually used to save energy. In the PSM the device remains in active and sleep state in a cyclic manner [6]. This complete period of a sleep and active state is referred as beacon interval. Various kinds of modifications in PSM are proposed as Adaptive PSM, Intelligent PSM, Opportunistic PSM and Mobility aware PSM. In adaptive PSM if data is not destined to any of the stations (STA) then the STA will not go to the sleep state immediately, but it will wait for a short time, called time out interval, so that the delay due to sleeping will be reduced [7]. In Intelligent PSM, STA does not get activated after each beacon frame reception, but the optimal activation time is decided by the access point (AP) and the activation time is the integer multiple of the beacon interval [8]. In case of OPSM the STA wait to be active for optimal time that require least energy consumption. This optimal time is considered as the time when AP is not serving any other STA [9]. In case of mobility aware PSM the mobility of user of traffic pattern is considered to create more sleep opportunity for a STA. In this PSM the effective buffer size is considered, when user is far from the STA. AP buffers the data and then sends it to higher data rate to save the time and energy [10]. Moreover cooperation between power saving mechanisms of front end and back end sub-network is desirable to further improve the network performance [6, 11].

It is observed that channel quality and offered traffic to the wireless network are important criteria which directly affect the network performance in terms of throughput [12]. Rate adaptation algorithm is one of the popular approach which improves the network throughput even through the channel quality is assumed to be poor or there is a collision. Various criteria for adaptation of the data rate are proposed in literature. Rate adaptation criteria can be categorized in two parts: statistical feedback criteria like retry count and the signal measurement criteria like RTS/CTS etc. In [13] practical rate adaptation algorithm, for multirate IEEE 802.11 WLANs, is proposed using both the mentioned criteria. In [14] an efficient rate adaption algorithm is proposed using fragmentation of the frame to avoid fading and collision simultaneously. In [15] a robust rate adaptation algorithm for 802.11 wireless networks is proposed using short term loss ratio and RTS/CTS protocol. In [16] link

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rate adaptation along with sleep mechanism is proposed for 10 Gigabit PON. But none of the paper is utilizing rate adaptation for energy saving along with PSM. Therefore in this paper energy efficient rate adaptation algorithm (EERAA) is proposed which applies rate adaptation mechanism to achieve energy efficiency at wireless front end during active state of a beacon interval for FiWi access network.

III. Problem Formulation

Subsection A deals with notations used to formulate problem domain. In sub section B a detailed description of PSM is given and energy analysis of PSM is done in sub section C.

A. Notations

L_D : Data frame length in bytes

L_A : Acknowledge (ACK) frame length in bytes

R_D : Set of all possible data rates for data transmission in IEEE 802.11a standard

R_A : Set of all possible data rates for ACK transmission IEEE 802.11a standard

P_0 : Transmission power required to transmit the data L_D at 6 Mbps

P_{ac} : Power consumption during active state

P_{sl} : Power consumption during sleep state

T_{ac} : Time spent during active state

T_{sl} : Time spent during sleep state

T_D : Transmission time for data frame

T_{ACK}: Transmission time for ACK frame

T_{PA}: Time to transmit the preamble

T_{SIC} : Time to transmit the signal field

T_{SYM} : Time to transmit the one symbol of the 802.11a WLAN

N_{DBPS} : Number of data bits encoded within one symbol

B. Power Saving Mode (PSM)

This subsection describes legacy PSM used at front end wireless sub-network. It consists of two states; sleep and active state as shown in fig. 2. In active state actual transmission takes place from AP to a STA while in case of sleep state the station remains turn off till the arrival of next intimation from AP. AP synchronizes various STAs by broadcasting beacon frames periodically, which consists of a traffic indicate map (TIM) field, indicating the availability of data for various STAs. On reception of beacon frame all the STAs switch themselves into active state. If the data is not destined to any of the STA, they immediately go to sleep state till the arrival of next beacon frame.

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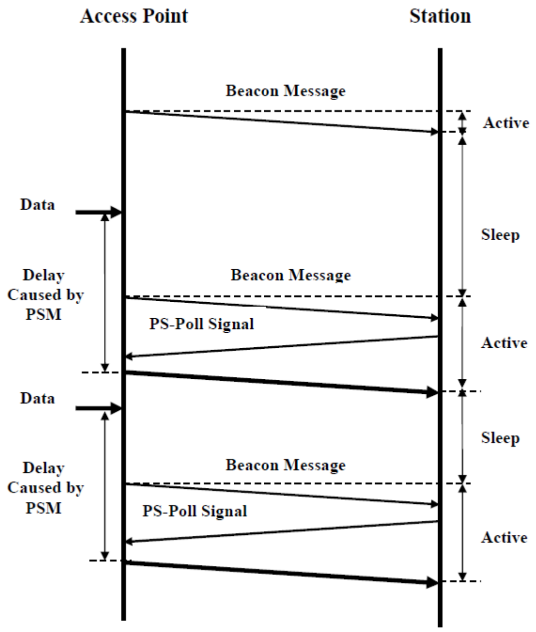

Fig. 2. Illustration of PSM for front end of FiWi network

However if the data is destined to any STA, it sends back a PS-Poll signal to AP indicating that it is ready to receive the data. After receiving PS-Poll signal all the buffered data is transmitted by AP to the destined STA. Immediately after completion of data transmission STA moves into sleep state till the arrival of next beacon frame.

During sleep state of the STA data may arrive at AP, which is buffered and released in next active state of the STA. In this way legacy PSM saves energy consumption by having the provision of sleep state. However buffering the data at AP during sleep state introduces buffering delay, which need to be considered.

C. Energy analysis of PSM

In PSM a beacon interval consists of two states namely sleep and active states. The overall energy consumption is given by-

$$E = E_{ac} + E_{sl} \tag{1}$$

Where $E_{ac} = P_{ac}T_{ac}$

and $E_{sl} = P_{sl}T_{sl}$

Since sleep state consumes less energy than active state; all previous works emphasize on increasing the sleeping opportunity of the device and making it energy efficient. However energy consumption during active state may also play crucial role, which has not been addressed so far. This subsection analyses various factors affecting the energy consumption during active state. Front end sub-network is considered as IEEE 802.11a WLAN for analysis. In active state, energy consumption depends on T_{ac} and P_{ac}. For WLAN, T_{ACK} is considered to be constant and T_{ac} is given as [17]

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$$T_{ac} = T_{PA} + T_{SIC} + T_{SYM}\left[\frac{16+8\,L_D+6}{N_{DBPS}(R_D)}\right] \tag{2}$$

It is clear from equation (2) that T_{ac} is a function of frame length L_D and transmission rate R_D. IEEE 802.11 a supports eight data rates R_D = {6, 9, 12, 18, 24, 36, 48, 54}. Various fixed parameters of WLAN sub-network are given in table I.

Table I. Parameters of IEEE 802.11a

Parameter	**Value**
T_{PA}	16 µs
T_{SIC}	4 µs
T_{SYM}	4 µs
$\mathbf{N_{DBPS}}$	4

Another factor affecting active state energy consumption is P_{ac}. The necessary active power for a certain service requirement depends on various factors like the transmission rate, the distance between communicating devices, the channel characteristics etc. For a time invariant channel with fixed distance between transmitter and receiver estimated active power consumption is used for analysis.

Let P_o be the estimated power consumption for transmission of one packet with minimum possible data rate that is 6 Mbps then active state energy consumption at different data rates for a single packet can be calculated and given in table II [17].

Table II. Energy consumption during active state at variou data rates

S. No.	**Data Rate (R_D)**	**Data Transmit Time (T_{ac})**	**Power Consumption (P_{ac})**	**Energy Consumption ($E = P_{ac.}\ T_{ac}$)**
1.	6 Mbps	1360 µs	P_0	1360 P_0
2.	9 Mbps	912 µs	2 P_0	1824 P_0
3.	12 Mbps	692 µs	2 P_0	1384 P_0
4.	18 Mbps	468 µs	4 P_0	1872 P_0
5.	24 Mbps	356 µs	8 P_0	2848 P_0
6.	36 Mbps	244 µs	16 P_0	3904 P_0
7.	48 Mbps	188 µs	32 P_0	6016 P_0
8.	54 Mbps	172 µs	64 P_0	11008 P_0

It can be seen from table II that lower data rate needs more time to transmit the data but requires less transmit power. Hence energy consumption is reduced by transmission on lower data rate than the higher data rate. However most of the work done so far tries to increase sleeping to gain energy efficiency. For considered network we can also caculate energy required during sleep state.

A complete beacon interval is the combination of T_{sl}+ T_{ac}. For the beacon interval of 100ms, T_{sl} can be calculated as:

$$T_{sl} = 100ms - T_{ac}$$

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Similar to the active state, sleep state energy consumption at different data rates for a single packet with constant sleep power P_{sl}, can be calculated and is given in table III.

Table III. Energy consumption during sleep state at various data rates

s.no	**Data Rate (R_D)**	**Sleeping Time (T_{sl})**	**Energy Consumption ($E_{Sl} = P_{sl}\, T_{sl}$)**
1.	6 Mbps	98.64ms	98.64 P_{sl}
2.	9 Mbps	99.088ms	99.088 P_{sl}
3.	12 Mbps	99.308ms	99.308 P_{sl}
4.	18 Mbps	99.532ms	99.532 P_{sl}
5.	24 Mbps	99.644ms	99.644 P_{sl}
6.	36 Mbps	99.756ms	99.756 P_{sl}
7.	48 Mbps	99.812ms	99.812 P_{sl}
8.	54 Mbps	99.828ms	99.828 P_{sl}

It can be observed from table that transmission on higher data rates provide more sleeping opportunity but values of sleeping time is not significantly reduced as data rates are increased. Therefore reduction in energy consumption due to more sleeping opportunity is not very significant. On the other hand, it is evident from table II that energy consumption in active state has major impact on data rate. Higher the data rate more is the energy consumption. So proposed algorithm tries to save the energy during active state and transmits the data on lower data rate without affecting the performance in terms of delay. This significantly increases the energy efficiency at front end of FiWi network.

IV. Proposed Algorithm

Transmission on lower data rate consumes less energy as compared to higher data rate. The proposed algorithm mainly focuses on selecting lower data rate (while maintaining transmission delay within specified limit) during active state of a beacon interval from the set of available data rates for IEEE standard 802.11a. Minimum data rate on which transmission takes place within prescribed transmission delay is called optimal data rate. This facilitates reduction in active state energy consumption of front end. For considering fixed energy consumption at back-end, proposed approach will contribute to significant reduction in overall energy consumption with maintaining the quality of service in terms of transmission delay of FiWi network .

Subsection A gives the various notations used in energy efficient rate adaptive algorithm. Subsection B describes the Energy Efficient Rate Adaptation Algorithm (EERAA).

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A. Notations

B: Current queue or buffer size

Dc : Delay constraint

R_D : Set of all possible data rates for IEEE 802.11a standard

R_i: Assigned data rate for transmission in active state of current beacon interval

R_f: Estimated future data rate for next beacon interval

B. Energy Efficient Rate Adaptation Algorithm (EERAA)

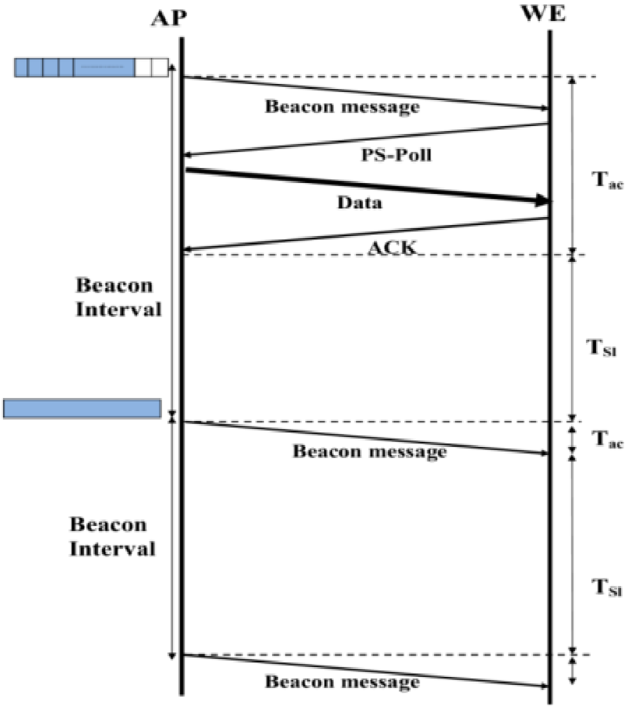

Fig. 3. Energy Efficient Rate Adaptation Algorithm along with PSM

Fig.3. shows the PSM with proposed Energy Efficient Rate Adaptation Algorithm. Rate adaptation is applied to modify the existing PSM for further reduction in energy consumption of active state of a beacon interval. In general data transmission is carried out with highest possible data rate, so that device can get more sleeping opportunities with minimum transmission delay. The EERAA proposes the adaptive data rate for transmission, which is the function of previous traffic arrival pattern. It permits one step increase (R_i to R_{i+1}) or decrease (R_i to R_{i-1}) from its current data rate with maintaining transmission delay within the prescribed limit. This facilitates the data transmission at lower possible data rates as compared to fixed higher data rate transmission. This results in reduction in energy consumption of a complete beacon interval. The different parameters used in proposed algorithm are as follows :

Delay constraint (D_C)

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It is the minimum time required to transmit the data when the system is operated on maximum possible data rate and can be given by-

$$D_C = \frac{Max\ buffer\ size}{R_{Dmax}}$$

For IEEE 802.11a WLAN the maximum possible data rate is 54 Mbps, hence-

$$D_C = \frac{Max\ buffer\ size}{54\ Mbps}$$

Future estimated rate (R_f)

It is the data rate which is calculated on the basis of traffic arrival pattern of previous N beacon intervals. Let B_{avg} be the average buffer data, then the future estimated rate is given as:

$$R_f = \frac{B_{avg}}{D_C}$$

Statement of algorithm

EERAA states that, "the current data rate R_i will get increased to R_{i+1} if $D_C<(B\div R_i)$While the current data rate R_i will get decreased to R_{i-1} if $R_f < R_{i-1}$. if both the conditions are false, then the transmission is carried out at the same data rate R_i".

Pseudo Code

1. Calculate D_C.
2. Set an array $R_D = \{6, 9, 12, 18, 24, 36, 48, 54\}$
3. Sender is in active state with current Data rate R_i

   HERE: At the end of next beacon interval
4. Calculate the average buffed data based on previous N beacon interval.
5. Calculate the R_f based on average buffed data and D_C.
6. Check the conditions -

   If $D_C<B\div R_i$

   $R_i = R_{i+1}$

   Else If $R_f<R_{i-1}$

   $R_i = R_{i-1}$

   Else transmit data with current data rate R_i
7. Jump to label HERE

V. RESULTS

This section presents the simulation results showing comparison of energy consumption for various fixed data rate schemes and EERAA. Fixed data rate scheme refers to transmission on one fixed rate. We have considered IEEE 802.11a for EERAA, which have different possible data rates {6, 9, 12, 18, 24, 36, 48, and 54}. In this system data is transmitted on highest possible data rate, to increase

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the sleeping opportunities. The system switches to lower data rate only in case of either poor channel quality or distance between transmitter and receiver get increased. Transmission on higher data rate consumes more active state energy. Therefore our algorithm tries to save the energy during active state and can transmit the data on lower data rate without affecting the performance in terms of delay. In this way it is possible to achieve trade-off between energy consumption and transmission delay.

For simulation a fixed distance point to point link between an AP and a router has been considered. The average energy for transmission on fixed rate and EERAA has been calculated. Rate assignment or switching is completely based on future estimated rate by previous packet arrival pattern, delay constrain for specific service and current queue size. For simulation following parameters are considered as shown in table IV.

TABLE IV PARAMETER SETTING

Parameter	Value
Packet length (L_D)	1000 Bytes
Max. Buffer size	100 packet
Beacon interval	100ms
P_0	10W
P_{sl}	3W

Simulation started from end of the beacon interval i.e. sleep period is just over and AP has some stored packet in its buffer. The estimated rate for the current queue size decides the current link rate. This current link rate either increases or decreases from its current value according to the traffic arrival pattern.

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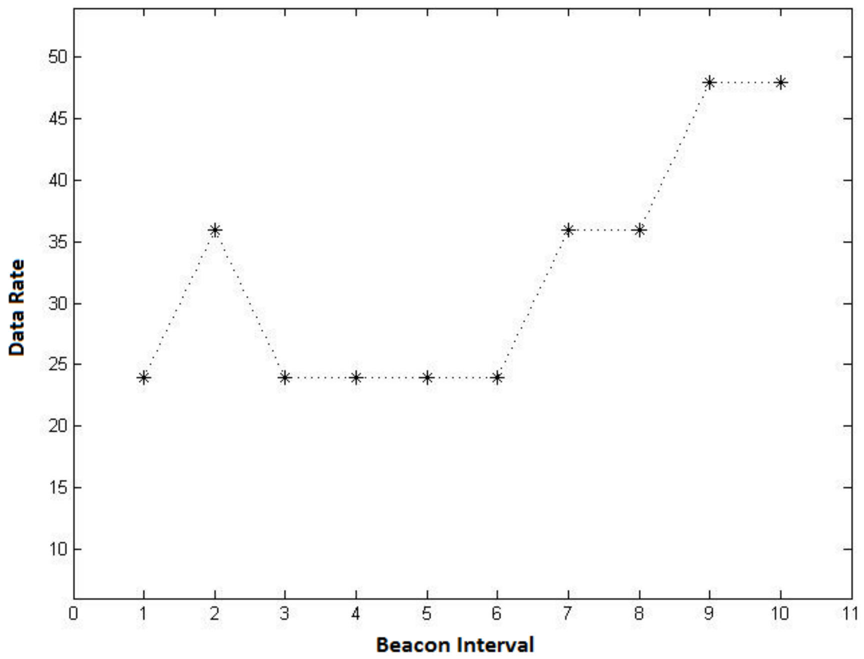

Fig. 4. Rate switching for various beacon intervals

Fig. 4. shows the rate switching during each beacon interval. It can be shown that the current data rate of the link can be incremented by the value of next index or decremented by value of previous index from standard set of data rates. The purpose of rate switching in the EERAA is to reduce the energy consumption during active period that will be clear from the subsequent results.

In order to compare energy consumption for proposed EERAA and various fixed data rate schemes, energy consumption during active state and sleep state is calculated. The total energy consumption for different traffic load is shown in fig. 5. It can be seen that the total energy consumed for data transmission at 54 Mbps scheme is maximum whereas it is minimum at 24Mbps scheme. EERAA maintains the data rate in between 24 Mbps and 54 Mbps schemes according to the accumulated load in buffer, such that the buffer will empty completely within the predefined delay. This will reduce the overall energy without affecting the delay performance of the network.

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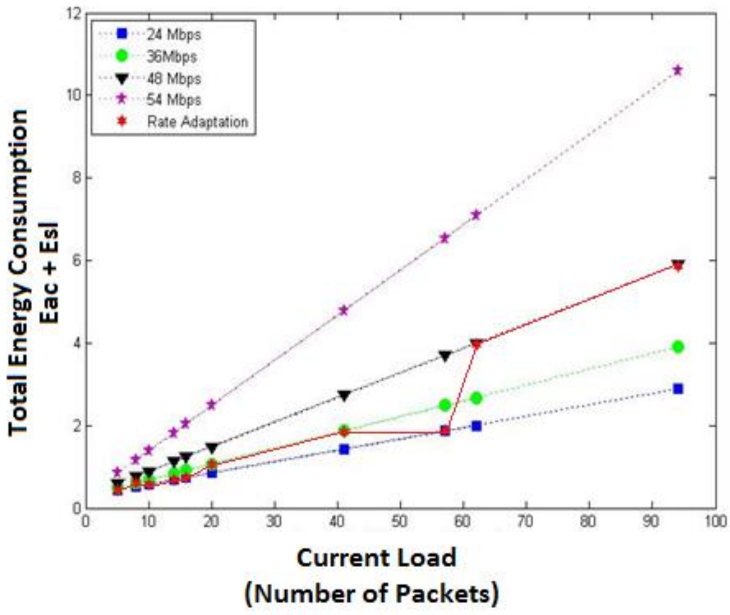

Fig.5. Total energy consumption during a beacon interval

Fig. 6 shows the average energy consumption during active state for different fixed data rate schemes and EERAA. It is evident that EERAA consumes less energy than that of two higher data rate schemes 48 and 54 Mbps.

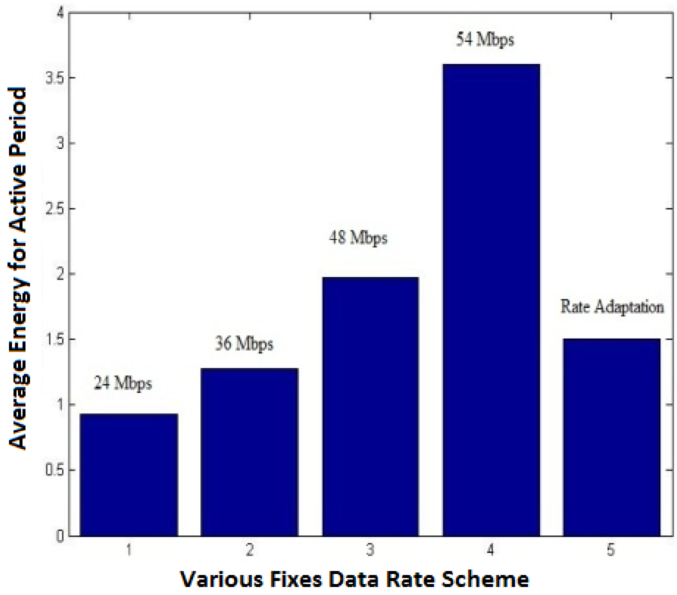

Fig.6. Average energy consumption during active state

Similarly energy consumption for active state, sleep state and overall energy consumption for different fixed data rate schemes and EERAA is compared in fig.7. As the energy consumption during sleep state is already very less and almost same for all the schemes, the active state energy

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consumption plays an important role in the total energy consumption. The EERAA effectively reduces total energy consumption during a beacon interval which is clear from fig. 7.

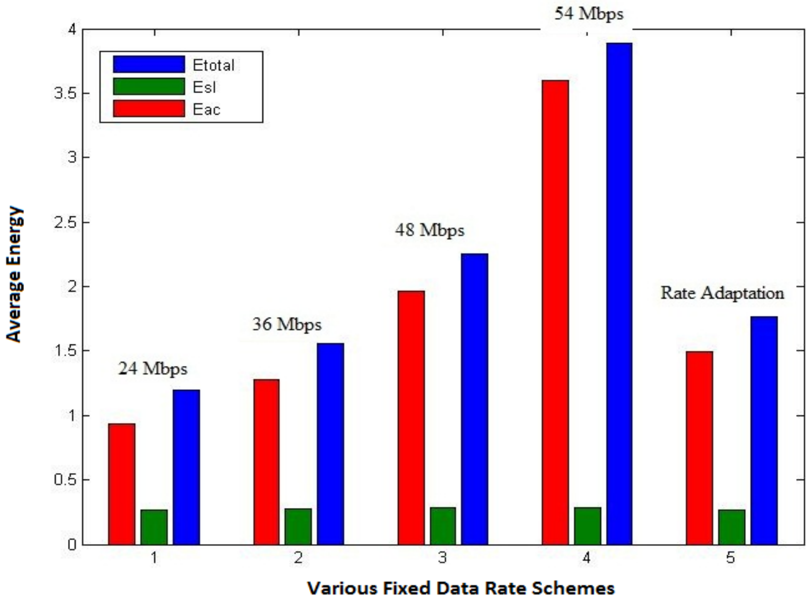

Fig.7. Overall Energy Consumption Analysis

It is well known that lower data rate scheme requires more transmission delay as compared to high data rate scheme contrarily high data rate schemes transmit the data rapidly, but require more active energy consumption. On the other hand EERAA tries to maintain tradeoff between required transmission delay and active energy consumption which is clear from fig. 7 and 8. Hence EERAA gives a better trade-off for delay and energy consumtion as compared to various fixed data rates schmes.

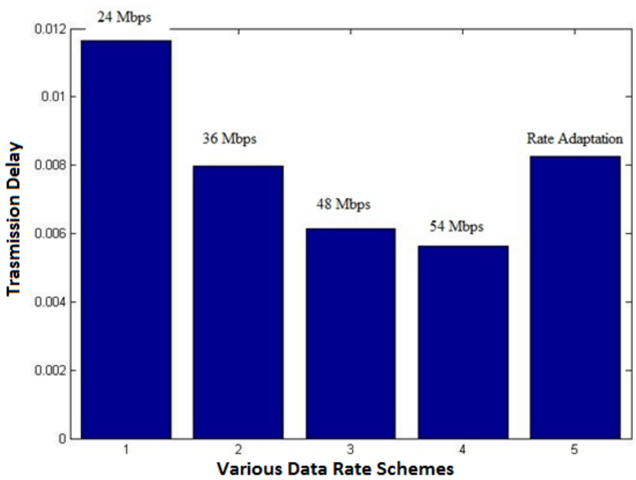

Fig.8. Transmission Delay

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VI. CONCLUSION

The proposed algorithm tries to reduce energy consumption of front end of FiWi network during active state of transmission by using the concept of rate adaptation method. Although, the principle of rate adaptation is widely used to maintain quality of transmission in case of poor channel conditions. But, its application is novel for reducing energy consumption during active state of transmission. It also maintains transmission delay within specified tolerable limit. Hence it may offer great candidature as energy efficient technique among various existing techniques for FiWi access networks.

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