

E²-DLNA: An Improved Energy-Efficiency Mechanism for DLNA

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Abstract—As the explosive growth of mobile networks, green mobile networks have been studied extensively. DLNA protocol, widely used in smart home, does not take any consideration for power saving. In this paper, we propose an energy-efficient mechanism for DLNA (E²-DLNA), which can achieve balance between QoS provision and energy efficiency. The core network condition estimation algorithm TES used in E²-DLNA can help Mobile Handheld Devices (MHD) adjust its packets-sending strategy according to estimated network condition. In this way, MHDs can dramatically reduce the unnecessary multicasting messages. Our experimental results show the effectiveness of E²-DLNA. Energy consumption can be reduced 10-30%.

Index Terms—DLNA; Smart Home; Green Mobile Networks; Energy-Efficiency; QoS

I. INTRODUCTION

The wide availability of inexpensive smart devices, such as Smart Phone and Smart TV, has recently led to the rapid proliferation of Smart Home [1] [2]. Increasingly, the use of these smart devices is expected to move from more traditional computer applications to new consumer-oriented applications currently provided by stand-alone devices. Industry initiatives, such as DLNA, IGRS, OSGi, AirPort, Miracast etc [3] [4] [5], aim at enabling smart home by ensuring interoperability among networked devices from the Consumer Electronics (CE), Mobile and Personal Computer (PC) industries. In particular, smart devices with their increasing multimedia and networking capabilities are expected to be first-class citizens in smart home ecosystem.

Digital Living Network Alliance (DLNA) [5] is one of the popular smart home standards. In recent years, more and more applications build in DLNA (e.g. [6] [7]). DLNA interoperability guidelines addressed home networked devices which are in general static and not energy-limited. The new version of the DLNA guidelines introduces Mobile Handheld Devices (MHD), which are in general mobile, energy-limited devices, such as smart phone, tablet, and portable music players. The new guidelines address a number of issues related to operating MHDs in a DLNA smart home network. To connect to a DLNA network, an MHD needs to connect via an Access Point, which bridges between the MHD domain and the rest of the home network.

In DLNA smart home network, heterogeneity occurs in many aspects: hardware, software platforms, network

protocols, and service providers. It is difficult to show the source on computers on another device. It is expected that this trend will continue, while in parallel the number of connected services/devices will explode. To improve the integration of DLNA-based devices, many studies attempted to extend DLNA mechanism [8] [9].

The new guidelines specify only default devices management architecture to support MHDs. When an MHD is connected to the smart home network using a wireless bearer, default architecture may not work well. Wired channel is reliable than wireless channel, because wireless channel is easy impacted by signal attenuation, interference, noise and other factors [10]. Default devices management architecture is designed for wired network, not considering unreliable wireless connection. The default architecture can't ensure QoS, and bad wireless connection causes increased power consumption for MHDs. Consumers would like to be able to use their MHDs to connect to the smart home networks without noticing a significant reduction in the battery duration of their devices. Therefore, there is a need for a new mechanism that would manage MHDs to save battery power.

The challenge is to minimize energy consumption without significantly compromising the user experience. In this paper, we present our proposal Energy-Efficiency DLNA (E²-DLNA) mechanism. The proposed mechanism can achieve balance between QoS provision and energy efficiency. The core network condition estimation algorithm TES used in E²-DLNA can help MHDs adjust its packets-sending strategy according to estimated network condition.

The rest of this paper is organized as follows: In Section II we present the related work in this area. In Section III we present a brief overview of the DLNA devices management architecture. In Section IV we describe the proposed E²-DLNA mechanism in detail. In Section V we present the performance evaluation results. Finally, in Section VI we give the conclusions of this work.

II. RELATED WORK

Smart home early energy-efficiency research focused on appliances [11]. With the popularity of mobile devices in the smart home, researchers have begun to pay more attention to energy-efficiency issues in mobile devices. [12] [13] [14] are presented in the future smart home will

be a complex network. Since the Internet Protocol (IP) horizontally integrates the control mechanism between heterogeneous networks and their extensions, heterogeneous network convergence would provide a tremendous opportunity for future advanced smart home. In the smart home, DLNA adapted to this trend.

Two mainstream network energy saving methods described in [15]. The first is based on putting network components to sleep during idle times. The second is based on adapting the rate of network operation to the offered workload. The authors show that both sleeping and rate-adaptation are valuable depending on the power profile of network equipment and the utilization of the network itself. Both methods are widely used in the study smart home wireless network energy saving.

In wireless network many energy saving methods work on MAC layer [16] [17]. These methods are only concerned with energy issues on MAC layer, they less consider the characteristics of the upper layer and propose better solutions. Smart home protocols like DLNA, there are some common characteristics on application layer, such as service discovery, work with AP, wireless network etc. Using these common characteristics we can save more energy on application layer than MAC layer.

A variety of algorithms to improve service discovery performance are proposed by [18]. Random delay continuous transmission algorithm consumes fewer resources, but the random delay is easy to cause network storms. Planned delay continuous transmission algorithm improves the success rate of data transmission, but increases implementation complexity. To obtain the entire network information, it also needs to send control packets, which is not conducive to energy-efficiency. Reduction broadcast packets loss rate method is proposed by [19]. Introducing the maximum query time (MX). Devices by interval MX reduce duplication packet transmission, reducing packet loss rate. But the author does not give the MX selection method, if the MX is too long, it will increase the network delay. Too short MX will cause the algorithm has no effect. SOA-based DLNA Web services framework is proposed by [20], it makes DLNA compatible with existing Web services. Although it improved the device compatibility, still does not solve the problem of energy consumption with DLNA.

More researchers concerned about green mobile networks [23] effects. A gateway with Bluetooth is proposed by [21]. In idle time, DLNA devices use Bluetooth connection to reduce transmission energy consumption. However, this method has higher requirements on the gateway and devices, not all devices are configured Bluetooth. A new energy-efficiency service discovery algorithm SANDMAN is proposed by [22]. The main idea is to synchronize the cluster nodes sleep to save energy. It has better performance in Ad hoc network, but it is not suitable for this method in WLAN, because AP is the center of the network. And this algorithm also has the cluster head node serious issues of energy consumption.

III. DEVICE MANAGEMENT ARCHITECTURE

DLNA interoperability guidelines defined the device management architecture. There are two main types of nodes Control Point (CP) and Root Device (RD) [19]. RDs provide a variety of services to CPs, so in this paper RD will be called Service Point (SP). Devices defined in DLNA can belong to two types of nodes. When DLNA devices enter LAN/WLAN area, SPs send advertise information to other DLNA devices via multicast, announcements online status, as well as to provide services. CPs send search information and find some interesting services via multicast. When there is an SP satisfy the query that returns response messages via unicast. After CP gets response, it uses unicast to request. In Figure 1 shows devices discovery and services discovery mechanism.

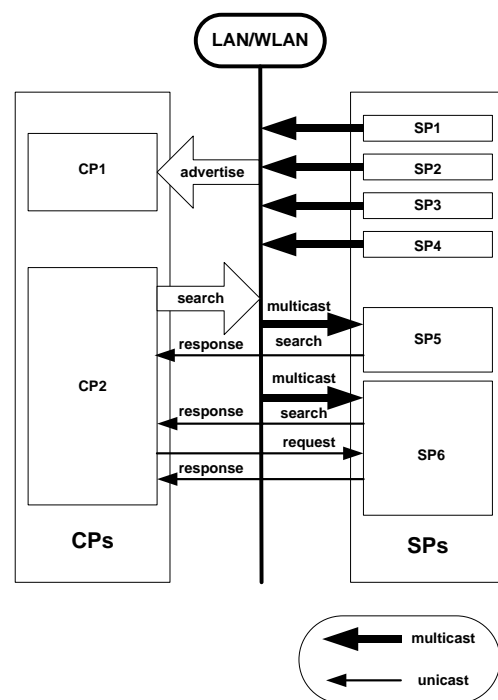


Figure 1. Devices discovery and services discovery

Devices use UDP to send the same packet multiple times to ensure the normal operation and higher QoS. Sending packets frequency is defined as f . In actual applications sending frequency is a fixed empirical value [24]. In the wired network, the channel quality is good, fixed f can achieve a good effect, but in the wireless network it may not achieve good effect. MHD using wireless transmission, fixed f can't ensure the packets' arrive. When the channel quality is poor, unreliable UDP transmission protocol will lead to high packets loss rate, low f can't satisfy the needs of QoS, and high f will lead to a waste of energy.

Fixed frequency means that a node multicast times is f , response frequency is f^2 . The number of nodes is n , each node processes up to $(n-1) \times (f + f^2)$ multicast packets. In wireless transmission, the more data packets to be processed, the more energy it will consume.

IV. E²-DLNA MECHANISM

A. Energy Model

MHD energy consumption model as follows:

$$E_{total} = E_{tx} + E_{rx} + E_{idle} \quad (1)$$

E_{total} is total energy consumed by MHD. E_{tx} is energy consumed by data transmission. E_{rx} is energy consumed by data received. E_{idle} is device idle phase energy consumption. If MDH without any sleep mechanism, then E_{idle} will be a constant value within a fixed time.

Packets loss rate has greatest impact on the user experience in the DLNA application. Define all nodes send data packets when the frequency $f \geq 1$, all the necessary data packets are received at least once as the best quality of service. Define service quality model is as follows.

$$Q = \sum_{i=1}^n \left[1 - (1 - P_i)^{f_i} \geq 0.9 \right] \quad (2)$$

$Q \in \{x \mid 0 \leq x \leq n\}$. When Q is closer to n , it means the better quality of service. When Q is closer to 0, it means the poorer quality of service. When the probability of nodes receiving multicast packets is greater than or equal 0.9, it means good quality of service. The number of nodes in the network is n . The probability of successful transmission is P .

Energy saving method's utility function minimization problem is as follows:

$$\begin{aligned} & \text{Minimum } E_{total} \\ & \text{Subject to } Q = n \end{aligned} \quad (3)$$

The main objective of energy saving method is to meet the constraint condition and make E_{total} minimum.

B. Energy Model Analysis

The number of bits to be transmitted is N . The number of bits to be received is R . N/P means the needs to successfully transmit the N bit data, the required number of bits actually transmitted. E_{et} is the energy per bit for the transfer. E_{er} is the energy per bit received.

$$E_{tx} = \frac{N}{P} \cdot E_{et} \quad (4)$$

$$E_{rx} = R \cdot E_{er} \quad (5)$$

The number of requests is N_{req} . A request packet length is L_{req} . Because different requests have different packet lengths, for convenience, the packet length takes the average. N_{adv} is the number of advertise packets. L_{adv} is length of the advertise packet. N_{resp} is the number of response to the request. The response packet length is L_{resp} . R_{req} is the number of received request packets. R_{adv} is the number of received advertise packets.

$$\begin{aligned} N &= N_{req} \cdot L_{req} \cdot f + N_{adv} \cdot L_{adv} \cdot f \\ &+ N_{resp} \cdot L_{resp} \cdot f \end{aligned} \quad (6)$$

$$R = R_{req} \cdot L_{req} + R_{adv} \cdot L_{adv} \quad (7)$$

T is the total running time. T_a is the interval between sending packets. S is the ratio of the SP which can satisfy service request.

$$N_{adv} = \frac{T}{T_a} \quad (8)$$

$$N_{resp} = S \cdot R_{req} \quad (9)$$

The number of nodes in the network is n . The number of i node's requests is N_{reqi} . The number of i node's advertises is N_{advi} . f_i is the i node's transmission frequency. P_i is the probability of i node's successful transmission.

$$R_{req} = \sum_{i=1}^{n-1} N_{reqi} \cdot f_i \cdot P_i \quad (10)$$

$$R_{adv} = \sum_{i=1}^{n-1} N_{advi} \cdot f_i \cdot P_i \quad (11)$$

Energy model are summarized as follows:

$$\begin{aligned} E_{total} &= \left(N_{req} \cdot L_{req} + \frac{T}{T_a} \right) \cdot \frac{f}{P} \cdot E_{et} + \left(\sum_{i=1}^{n-1} N_{reqi} \cdot f_i \cdot P_i \right) \\ &\cdot \left(\frac{f \cdot S \cdot L_{resp}}{P} \cdot E_{et} + L_{req} \cdot E_{er} \right) + \left(L_{adv} \cdot \sum_{i=1}^{n-1} \frac{T}{T_{ai}} \right) \cdot E_{er} \\ &+ E_{idle} \end{aligned} \quad (12)$$

During the whole running time (T), N_{req} is a fixed value. Packet length L will not change much, it can take the average. E_{et} and E_{er} are fixed value which are decided by the device transmission power and receive power. S does not change frequently. After analysis energy model can be deduced f , P , and T_a can affect energy consumption. In actual application, T_a is a constant, and it's less affected.

TABLE I. MODEL PARAMETERS

Parameter	Value
N_{req}	100
N_{adv}	360
L	1000 Byte
S	1
n	5
E_{et}	10 J/MB
E_{er}	7 J/MB

According to the equation, the energy consumed by MHD can be calculated under ideal conditions. Table I shows the model parameters. $T=3600s$. Using five kinds of strategies to send packets ($f \in \{1, 2, 3, 4, 5\}$).

According to the result of energy model shown in Figure 2. Found, using different strategies to send packets, which energy consumption have significantly different. When using the first strategy to sending data packets ($f=1$), the least energy consumption. With the f increases, the energy consumption is increasing. When $f=5$ is the

maximum energy consumption, and the largest interval between $f=4$. As the wireless network changed for better, the energy consumption is reduced, slowly approaching straight. This happens because the poor in a wireless network, the retransmission of packets need to consume large amounts of energy. When the wireless network is better, slowly reducing retransmission energy and eventually become stable values.

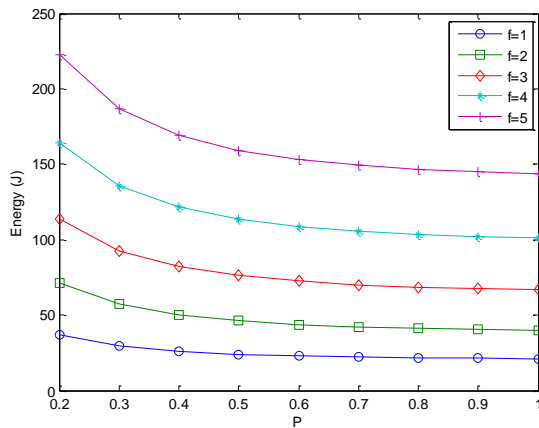


Figure 2. Compare different transmission strategies of energy consumption

Let E_{total} minimum you need to make f as small as possible, subject to $Q=n$. According to the value of current network P , choose the smallest f which can ensure QoS strategies and minimum energy consumption.

C. E^2 -DLNA Mechanism

We presented a mechanism of Energy-Efficient on DLNA (E^2 -DLNA). The core idea is to ensure QoS for different P and choose the best strategy to send packets. Wireless channel is easy impacted by signal attenuation, interference, noise and other factors. As the channel condition will change with time and environment, the P is difficult to calculate. In [26] P is given the exact calculation method. But in actual network, using its calculation method to calculate P will take a lot of CPU resources, and it requires monitor in real time network conditions. This is not conducive to energy savings. We propose Test Statistics Estimate (TSE) algorithm, which we can take advantage of DLNA devices management feature to estimate the value of P .

The main idea of TSE algorithm (Algorithm 1) takes advantage of DLNA devices management feature, collecting new advertise packets, and the set of the new advertise packets is compared with the old one. If it found that the set of advertise packets have missing equipments, there is the phenomenon of network packets loss. P will be reduced according to strategies. If it found new set and old set are stable in a period of time, it's considered a relatively stable network. P will be increased according to the strategies. If it found exception packets received, it's considered network exception occurs. P will be reduced according to the strategies.

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E^2 -DLNA is described below:

Begin

When MHD entering a DLNA network runs TES algorithm, using initial strategy to send packets.

Periodic using the current strategy to send advertise packets, the cycle interval T_a .

$2T_a$ intervals to ensure other devices within the advertise packets are sent, began setting up a new strategy called TES algorithm.

According to the calculation, using the corresponding strategy send service request, service response and other data packets.

When the device exits normally DLNA network, then stop TES algorithm.

End

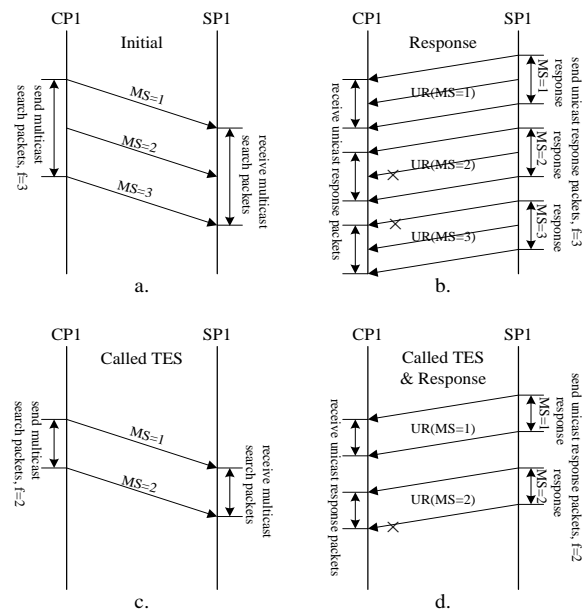


Figure 3. Electric current changes DLNA mechanism

In figure 3, we chose two nodes in the network CP1 and SP1 to show how E^2 -DLNA works. In the sample CP1 sending multicast packets, SP1 uses unicast to send response packets. In figure a, node CP1 uses initial strategy to send multicast search packets (MS). In figure b, SP1 receives all multicast search packets from CP1 and uses default strategy $f=3$ to send unicast response packets (UR). The symbol X indicates that the data packet has not arrived, but because of the large number of redundant packets, it does not affect the final result. When the time interval $2T_a$, CP1 and SP1 receiving all nodes' packets within a network, then call TES algorithm to calculate the current optimal strategy. In figure c and d, CP1 and SP1 are using the current optimal strategy to send packets. By comparing the figure a.b. and c.d. can be seen that E^2 -DLNA can significantly reduce redundant packet.

TABLE II. THE EXAMPLES' DATA SETS

Strategy	old_ADV	new_ADV	tmp_ADV	Situation	Evaluation
f=2	1, 2, 3	1, 3, 1, 2, 2, 3	1, 2, 3	keep	positive
	1, 2, 3	3, 4 ⁺ , 2 ⁺ , 3, 1, 1, 4 ⁺	1, 2 ⁺ , 3, 4 ⁺	join & leave	positive
	1, 2, 3	1, 3, 3, 4, 1, 2, 2	1, 2, 3, 4	exception join	negative
	1, 2, 3	3, 3, 1, 1	1, 3	exception leave	negative
	1, 2, 3	1, 4, 1, 3, 3	1, 3, 4	exception join & leave	negative
f=3	1, 2, 3	1, 1, 2, 2, 2, 3, 3, 3	1, 2, 3	keep	positive
	1, 2, 3	2 ⁺ , 2 ⁺ , 1, 2 ⁺ , 1, 1, 3, 3, 4 ⁺ , 3, 4 ⁺	1, 2 ⁺ , 3, 4 ⁺	join & leave	positive
	1, 2, 3	1, 1, 4, 2, 2, 3, 3, 2, 3	1, 2, 3, 4	exception join	negative
	1, 2, 3	1, 1, 1, 3, 3, 3	1, 3	exception leave	negative
	1, 2, 3	4, 3, 3, 1, 1, 1	1, 3, 4	exception join & leave	negative

Algorithm 1: *INIT* initialization parameters for the algorithm. P is the current estimate of the probability values of the network. ST is a set of strategies. ST is based on energy model analysis results. new_ADV , old_ADV are real-time and historical advertise packets set. *MergeRepeat* merge duplicate packets. *isTheSame* determines whether it is the same packet. *isNewADV* determines the new advertise packets, or not recorded but is normal advertise packets. *isLeaveADV*, *isTimeoutADV* determines whether a device is normal left.

We provide some simple examples to show how the algorithm works. The examples' data sets are shown in Table II.

In the first column of the table represents the use of strategy. We use three strategies in examples ($f \in \{1, 2, 3\}$). The second to the fourth column of the table respectively represents the samples sets of the old_ADV , new_ADV and tmp_ADV . X^* represents the packet format. X represents the equipment identification number. The symbol $*$ represents the function of the packet. There are three kinds of values the symbol $*$ can take. When the symbol shows void, it means the state of the device is keep, the symbol $+$ means join, and the symbol $-$ means leave. The new_ADV represents the set of real-time received packets. There will be repeated packets in it, and it needs the function of *MergeRepeat* to merge duplicate packets. The merged result sets uses the tmp_ADV to represent. The fifth column of the table represents the results of the analysis. By comparing the tmp_ADV and old_ADV , we analyze the situation which device receives packets. Finally, we make the evaluation. The sixth column of the table represents the results of the evaluation. When the result of evaluation is positive, we increase the value of P according to the strategy. On the contrary, when the result of evaluation is negative, we decrease the value of P .

Algorithm 1 TSE(INIT, P , ST , new_ADV , old_ADV)

```

1  if(INIT  $\equiv$  TRUE) then
2    f:=init_f(ST);
3    P:=init_P(ST);
4    SendMulticast(ExpNewInADV,f);
5  else
6    tmp_ADV := MergeRepeat(new_ADV);
7    tmp_Miss := old_ADV - tmp_ADV;
8    if(tmp_Miss  $\equiv$  NULL) then
9      if(isTheSame(tmp_ADV,old_ADV)) then
10       if(P  $\neq$  maxP(ST)) then incr(P, ST);
11     end if
12   else

```

```

13   if(isNewADV(tmp_ADV - old_ADV)  $\equiv$  TRUE) then
14     old_ADV := tmp_ADV;
15   else
16     if(P  $\neq$  minP(ST)) then decr(P, ST);
17   end if
18   end if
19   end if
20   else
21     if(isLeaveADV(tmp_Miss)  $\equiv$  TRUE) then
22       ||isTimeoutADV(tmp_Miss)  $\equiv$  TRUE) then
23       old_ADV := old_ADV  $\cap$  tmp_ADV;
24     else
25       if(P  $\neq$  minP(ST)) then decr(P, ST);
26     end if
27   end if
28   f:=getQP(P, ST);
29   end if
30   return f;

```

V. EVALUATION

We evaluate the performance of E²-DLNA using experiments in our indoor testbed with real environment, shown in Figure 4. We compare E²-DLNA to default mechanism in these experiments. All evaluations are carried out on ZTE U880 (core chipset Marvell PXA910, WLAN module 88W8787, maximum transmit power 20dBm.) [27] with Android platform version 2.2. We use NETGEAR KWGR614 as AP. All the wireless devices operate in 802.11g standard.

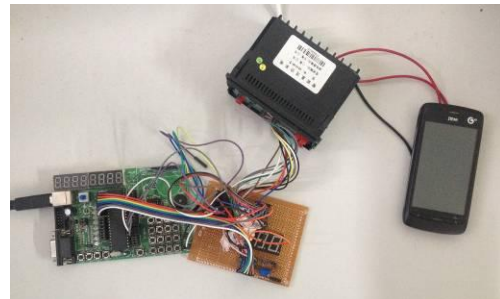


Figure 4. Experiment and measurement uses ZTE U880

We use 10 devices in our first experiment. It reflected power changes by measuring electric current [28]. Experiment parameters are shown in Table III.

Figure 5 and Figure 6 show the default mechanism and E²-DLNA of the current changes. In Figure 5, the default mechanism of current change is steep, and the change is obvious. The maximum peak reached 62mA, and minimum peak reached 40mA. In Figure 6, E²-DLNA of current change is gentle, and the change is not obvious.

Peak current is small, reaching only 45mA maximum. The peak is not equal because the energy transmitted is greater than the energy required to receive. Statistical results show that no matter which mechanism is used, the probability of successfully received packets is greater than 90% to satisfy the QoS requirements. From the figure we can find that in the first 100 seconds, the gap of the peak is larger, then the gap changes smaller. This is because the method of sending data packets has higher synchronization rate prone to transient network congestion, especially the wireless network is easier to lead packets loss. Random delay [18] is to solve network congestion problems in the common method. After running for a while each device sends data packets not with the same interval, the network reduces transient congestion. This method is also implemented in E²-DLNA.

TABLE III. EXPERIMENT PARAMETERS

Parameter	Value
MHD	ZTE U880
P _{tx}	20dBm
T	300s
L	1000 Byte
S	1
n	10
T _a	15s
N _{req}	20

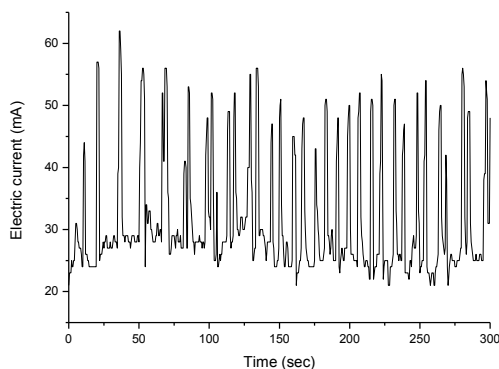


Figure 5. Electric current changes DLNA mechanism

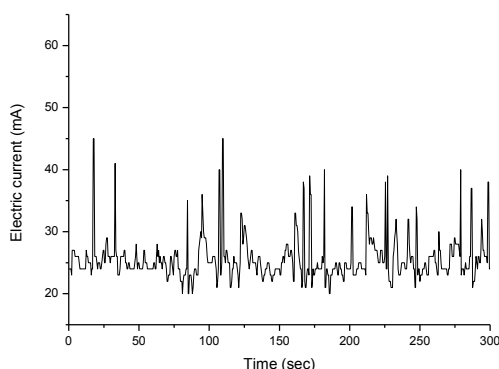
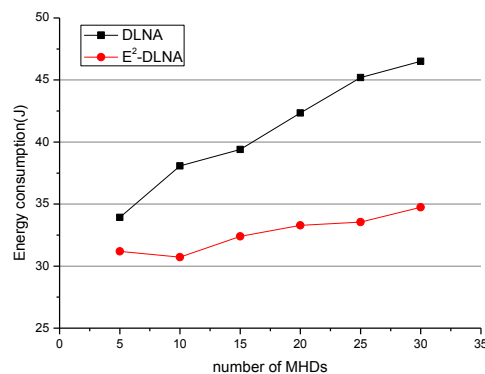
Figure 6. Electric current changes E²-DLNA mechanism

Figure 7. Compare the different number of devices of energy consumption

Use a different number of devices to compare the two mechanisms' power consumption. In this experiment, we use 5 to 30 devices to test energy consumption using different mechanisms. From Figure 7, we can find that when the number of devices increases, the use of the default mechanism obviously increased its energy consumption, and the energy consumption increases very fast. Using E²-DLNA, energy changes smoothly, and the energy consumption increases slowly.

We can see from the above experiment that when the amount of devices increases, E²-DLNA have more significant effect. Because when the amount of devices increases, default mechanism can't adapt to network condition change, there will be a lot of redundant data packets. This not only takes up the wireless bandwidth resources, but also consumes extra energy. E²-DLNA can estimate the current state of the network to send data packets using reasonable strategies. It can reduce redundant data packets, reduce instantaneous congestion, and it can save energy. From the results we found that the E²-DLNA can save 10-30% of the energy.

VI. CONCLUSION

In this paper, we presented a mechanism of energy-efficiency on DLNA: E²-DLNA. By theoretical analysis we found the main factors of the energy consumption. By TES estimated the current network environment, and given the reasonable strategy to achieve energy saving effect. Real environment experimental results show the effectiveness of E²-DLNA. MHDs' power consumption can be reduced 10-30%.

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