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Multi-Hop versus Overlay Networks: A Realistic Comparison Based on Energy Requirements and Latency

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Abstract— *This paper compares the energy and time needed to convey one information unit from source to destination using multi hop networks versus overlay networks. For a set of realistic parameters the paper will show that multi hopping with more than 50 relays will need more time than the overlay network and with respect of energy the usage of more than 6 relays is using more energy than the overlay network. The paper underlines the importance of the idle power value for such calculations.*

Index Terms—*cooperative wireless networks, energy saving*

1. INTRODUCTION

Multi-Hop networks have been introduced in order to tackle many relevant problems in communications, such as increasing network coverage, enhancing quality of service in the vicinity of the cell edge, disaster management communication systems and many others. Most researchers are considering multi-hop networking as a potential candidate to save energy. In the light of recent research on green wireless networks, multi-hop techniques are presented as an effective approach. However, to get a deeper insight on the possible advantages of multi-hop networks, they need to be investigated in a much closer manner, taking into account, among others, the overall energy expenditure. Indeed, typical studies consider mostly the sending power. However, a complete view should consider the overall power required to transfer information, namely transmitted power at the transmitting end, the power spent while receiving information at the receiving end as well as the power consumed while being idle at both ends.

This paper looks at the power and energy issues of a multi hop network including all three potential energy states of nodes (idle/receiving/sending). Results will be compared against the baseline case of an overlay cellular network. Moreover, to assess performance realistically this paper also compares the latency in both types of networks, another importance performance figure.

The state of the art in this field is based on a vast literature on routing in multi-hop networks such as [4,5], but to the best of our knowledge the comparison of those two network approaches with parameters derived from realistic measurement campaigns has not been presented so far.

The remainder of the paper is structured as follows: First we introduce the scenario under investigation, then we present the performance evaluation for each network, continuing with a comparison of both network types. Then we present the results achieved for a parameter set obtained in our measurement test-bed. Finally, conclusions are drawn.

2. SCENARIO UNDER INVESTIGATION

As given in Figure 1, a source *S* wants to convey one information unit to the destination *D*. The source *S* can transmit either through the overlay network or using the multi-hop chain. In case of the multi-hop network, the

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sender S would send the information over the chain of R relays, resulting thus in (R+1) hops. Note that the hops are carried out over short-range (sr) wireless links. Each node has three possible power states, namely the power for sending (P_s), power required for receiving (P_r) and the power consumption while being idle (P_i). We assume that only one node can transmit at a given time and therefore only one node is receiving at a time. Furthermore, the data transmission rate R_{sr} is the same for all communication links within the multi- hop chain.

If the source transmits the information unit through the overlay network, the information stream jumps directly to the base station BS. Form the BS the information is routed to the BS associated with the destination node and this BS will finally transmit the information unit to the destination node D. In this paper we only focus on the energy that is consumed by the source and destination and therefore we neglect the energy that is consumed by the overlay network while transferring the assumed reference information. Furthermore, we assume that there is no delay involved between two base stations. The transmission rate between the BS and any node is referred to as R_c. We define the ratio between R_{sr} and R_c as Z. Note that in general $Z >> 1$.

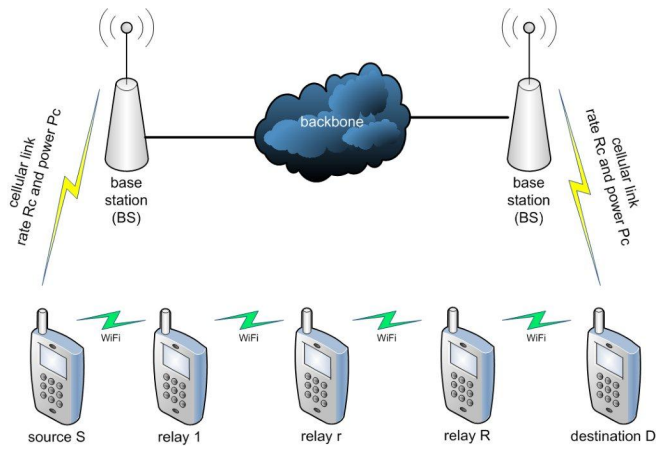

Figure 1: Scenarios under consideration: a) sending information through the overlay network (upper branch) and b) sending information through *R* repeaters (lower branch).

3. Performance Evaluation

In the following we evaluate analytically the performance for the two different scenarios in terms of energy and time.

3.1. The Overlay Network

The scenario of the overlay network is simple and straightforward. We assume that the source S transmits first a given information to its associated BS during a time t_c with a power expenditure P_s. While the source is *sending*, the destination node is in an *idle* state. In the next stage of the information transfer procedure the destination *receives* the information while the source remains *idle*. The receiving period is also t_c and the power consumption at receiving end is P_r. The energy E involved for the information exchange is given below:

$$E_{overlay} = P_s t_c + P_i t_c + P_r t_c + P_i t_c \quad (1)$$

$$E_{overlay} = (P_s + P_r + 2P_i)\, t_c. \quad (2)$$

The time T for the overlay exchange is the sum of the time for the upload and the download and therefore equals

$$T = t_c + t_c = 2\, t_c. \quad (3)$$

3.2. The Multi Hop Network

In the multi-hop network the energy calculation depends on the number of involved relays R. When one node is *sending* another node is *receiving*, while the remaining nodes are *idle*. As we have R relaying nodes, one source and one destination, the number of nodes that are idle equals always R (even though it is not always the case that the relays that are idle). In order to convey the full information (R+1) hops are needed. As given above the transmission time t_{sr} on the multi hop link is Z times smaller than t_c. The power values remain the same as given in the overlay scenario.

The overall energy in the multi-hop network is given by

$$E_{multi\text{-}hop} = (R+1)(P_s + P_r + RP_i)\, t_{sr}. \quad (4)$$

In the second order from it equals

$$E_{multi\text{-}hop} = R^2 P t_{sri} + R\,(P_s + P_r + P_i)\, t_{sr} + (P_s + P_r)\, t_{sr}. \quad (5)$$

The time that is needed to convey the information from source to destination is given by

$$T = (R+1) t_{sr}. \quad (6)$$

4. Realistic Performance Comparison

In this section the multi-hop and overlay cellular approaches are compared in terms of energy requirements and involved latency.

4.1. Latency

We start considering the time needed to convey the information unit. Both scenarios will require the same time to transmit the information ($t_{overlay} = t_{multi\text{-}hop}$) if

$$2t_c = (R+1)\, t_{sr}. \quad (7)$$

As $Z = t_c/t_{sr} = R_{sr}/R_c$, the number of relays R for equal transferring time in both scenarios is

$$R_{equal\ time} = 2Z - 1. \quad (8)$$

In other words the multi-hop scenario would be faster as long as the number of relays is smaller than 2Z-1. As Z is typically a relatively large number, the latency caused by

multi-hoping starts to get comparable to that of the cellular approach for a considerably large number of repeaters. In other words, in practical multi-hop scenarios, where the number of relaying nodes is low to moderate, latency is not an issue despite of the multiple hops involved.

4.2. Energy

For the energy scenario we compute when the same energy is consumed for both scenarios, that is to say

$$E_{\text{overlay}} = E_{\text{multi-hop.}} \quad (9)$$

From the results above we get

$$(P_s + P_r + 2P_i)\, t_c = R^2 P_i\, t_{sr} + R\,(P_s + P_r + P_i)\, t_{sr} + (P_s + P_r)\, t_{sr}. \quad (10)$$

As $Z = t_c/t_{sr}$, we obtain the following equation

$$R^2 + R\,(P_s+P_r+P_i)/P_i + [(1-Z)(P_s+P_r)-2ZP_i]/P_i = 0, \quad (11)$$

that we need to solve in order to determine R.

The number of relays R where both scenarios require the same energy is given by

$$R = -\frac{Ps+Pr+Pi}{2Pi} + \sqrt{\left(\frac{Ps+Pr+Pi}{2Pi}\right)^2 - \frac{(1-Z)(Ps+Pr)-2ZPi}{Pi}}. \quad (12)$$

The negative solution of this equation is neglected.

5. Realistic Parameters Derived from Measurements

In the following we measure real parameters to be then used in the previously derived results. The parameters are measured on commercial wireless devices, namely the smartphone Nokia N95 and N97. The results are an update to our previous results shown in [1]. We assume that the overlay network is realized by a cellular network and the multi-hop by R WiFi enabled mobile phones.

The energy measured when a device was connected to a WLAN network but not sending or receiving data, was considerably high in [1]. Therefore we have performed the measurements again both on the N95 with the newest firmware, and the N97. We used a set of small programs written in Qt/C++, to measure the sending, and receiving data rates, and the sending, receiving, and idle energy. The energy was measured with the Nokia Energy profiler [2]. As seen in [3] the values retrieved by the Energy Profiler [2] are verified by the measurements carried out with an Agilent instrument [3]. The new set of values that we obtained were similar than the previously measured, for sending and receiving data. But when the devices were connected to a WLAN network without sending or receiving we observed significant reduced values. Figure 2 shows the practical setup used to measure data rate and energy consumption of the wireless devices.

Therefore we will present results for two different idle power values for WiFi technology. The Z value is 27.8 based on the measured rates. As Z is highly dependent on the technology roadmap of the manufactures we present results for three different Z values, namely Z={13.9;27.8;55.7}. One value of Z was actually measured and the other two are representing the case when the cellular network becomes twice as fast (Z=13.9) or if the short range technology becomes faster (Z=55.7).

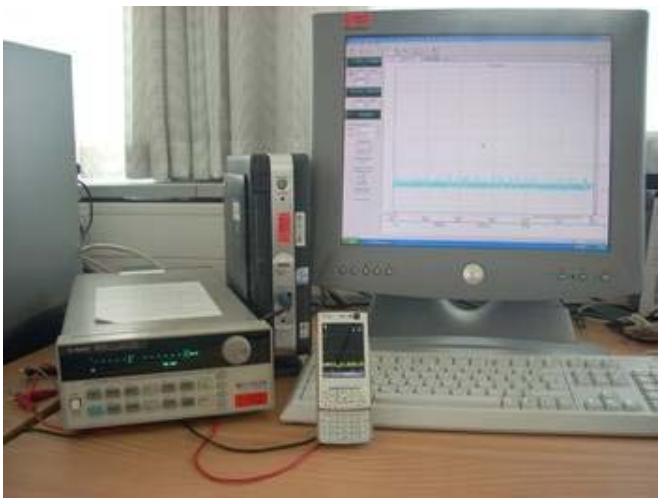

Figure 2: Energy testbed for mobile phones at Aalborg University using Agilent and Nokia Energy profiler.

Table I shows the practical values of the measured power values on commercial wireless devices.

TABLE I
PARAMETERS USED THROUGHOUT THE PERFORMANCE EVALUATION

Technology	*Parameter*	*Value*
WiFi	*P*s	1.629 W
	*P*r	1.375 W
	*P*i	0.0626 W or 1.00 W [1]
	R_{sr}	5.379 Mbit/s
Cellular	*P*s	1.314 W
	*P*r	1.314 W
	*P*i	0.066 W
	R_c	0.193 Mbit/s

6. Results

In the following we present the impact of the number of relays R versus the latency (section 6.1) and the energy (section 6.2) using the parameters given in the section above.

6.1. Latency

In Figure 3 the normalized latency versus the number of relays R is shown. The curve with the constant value around 10 is the latency given by the cellular overlay network. The

other three curves represent the multi hop network for different values of *Z*. While the middle curve is representing the actual measured *Z* value, the other two curves represent the situation when *Z* would be halved or doubled. *Z* will change over time as different improvements of cellular and the short-range technology take place.

The intersection of the curves of the overlay network and a multi hop network for a given value of *Z* is identifying the point where the latency of both communication systems is the same. For smaller values of *R* the multi hop network performs better than the overlay network and the other way around if *R* becomes larger.

The plot shows that the latency is over the cellular network is still larger than the multi hop network as long as the number of relays R is smaller than 25, 50, and 110 for the halved, real, and doubled Z value respectively.

The different values for *P*i in the short-range technology have no impact on the latency plot.

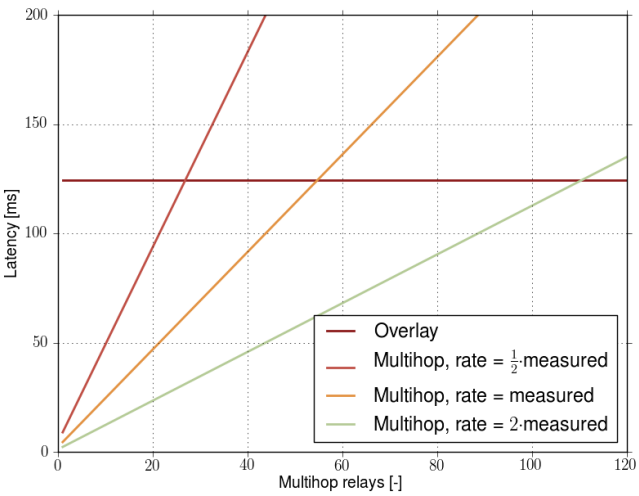

Figure 3: Latency versus number of relays *R* for *P*i=0.06W.

For an increased value of *P*i the number of relays that can be used in a multi hop network before it becomes slower than the overlay network is drastically reduced.

6.2. Energy

Now we focus on the energy consumed by the overlay and the multi-hop network. In order to investigate the impact of the P_i value we increase the value of P_i from 0.06 W to 1.00 W. This is in accordance with our paper in [1].

First we will set the idle power Pi in the short range technology back to 0.06W.

In Figure 4 and 5 the energy consumed versus the number of relays R is given for the overlay network and the multi hop network with the previously introduced three values of Z.

Also here the intersections of the curves identify the point where the energy in both communication systems is the same. For smaller values of *R* the multi-hop systems outperform the overlay network.

In Figure 4 the idle power of the short range technology is set to 0.06W. The point where the overlay network and the multi-hop network are using the same energy is *R*=19. Note, that for 19 relays the energy consumption is the same, but, as given in Figure 2, the time needed to convey the information is still larger in the overlay network. Doubling *Z* results in a number of *R*=30. Reducing *Z* to one half results in *R*=10. Nevertheless even if *Z* changes the *R* values achieved considering energy are always smaller than looking at the latency.

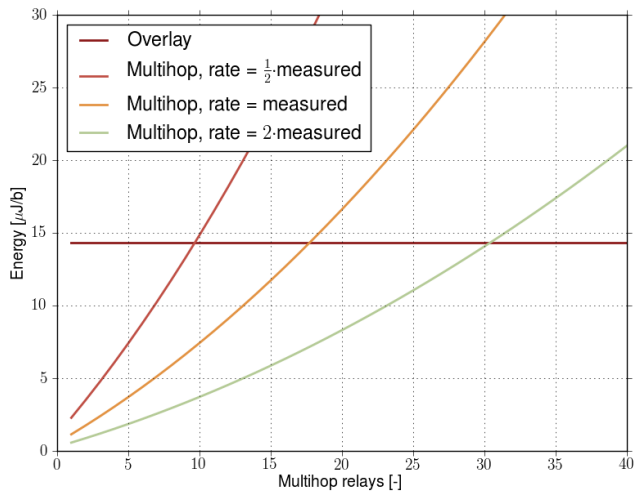

Figure 4: Energy versus number of relays *R* for *P*i=0.06W.

Figure 5 is now looking at P_i=1.00 W.

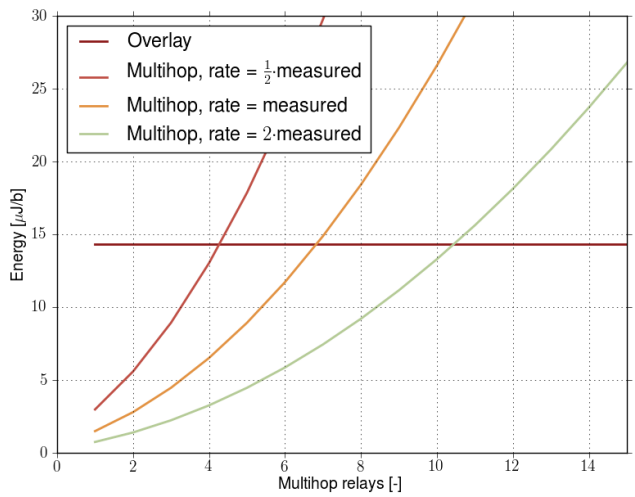

Figure 5: Energy versus number of relays *R* for *P*i=1.00W.

7. DISCUSSION

The present performance analysis is simplified in order to understand the basic concept of multi- hoping versus overlay networks. The number of relays that would favor one scenario over the other will change if some of the listed assumptions are relaxed. For example the limitation in the multi-hop network that only one node can send at the time has an impact on the number of idle nodes. If this limitation can be relaxed the number of relays involved in the multi-hop may increase and still the multi-hop network is in favor over the overlay network.

8. CONCLUSION

In this paper we have compared the transmission performance in terms of energy and latency between one sender and receiver using the overlay or a multi-hop network. A simplified analytical model is presented and a performance evaluation based on real measurement results for data rate and energy has been carried out. The aim of the paper was to understand when it is beneficial to use either the overlay or the multi hop network based on the number of relay R that is used in the multi-hop network. For the different technologies cellular 3G networks for the overlay and WiFi technology for the multi-hop network was assumed.

As a summary of the results we conclude that the number of relays in the multi hop network can be large (around 50) if only latency is considered, but it reduces dramatically if the energy is considered as well (as low as six). We note that the results may change as we relax the basic assumption for this paper, but the framework presented here is still valid.

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