SCALABILITY

Summary of MANET Email List Discussions

L. E. Miller, NIST, 6 March 2003

Subject: Re: Ad Hoc Network Scalability
Date: Thu, 05 Jul 2001 08:34:37 -0400
From: "M. Scott Corson" <mscorson@ix.netcom.com>
To: Joe Macker <macker@itd.nrl.navy.mil>, philippe.jacquet@inria.fr
CC: manet@itd.nrl.navy.mil

Actually, Matthias Grossglauser (AT&T Labs - Research), David Tse (University of California at Berkeley) have a very interesting throughput result (best paper Infocom 2001) for ad hoc networks.

Basic idea: Take a message you wish to send to some destination, break it up into N pieces, give those pieces to N different nodes that you randomly bump into as you walk around, eventually all N of those nodes will bump into the destination and give it their piece, effectively transferring the whole file.

This result shows that the average long-term throughput per source-destination pair can be kept *constant* even as the number of nodes per unit area increases. Of course, there is no bound on the message delivery latency or memory requirements of the network nodes, but a very interesting and rather counter-intuitive result nonetheless.

downloadable from http://www.ieee-infocom.org/2001/

-Scott

At 10:57 AM 6/29/01 -0400, Joe Macker wrote:
>At 07:21 PM 6/28/2001 +0200, you wrote:
>>It is clear that multihop impacts the performance.
>>In a recent paper (in information theory, I must look in my records), it is shown that the percentage of throughput in an ad hoc network of N users is at best of order 1/sqrt(N) in a 2D network with power law signal attenuation. The impact of routing makes that each packet has to be routed in an average of sqrt(N) hop.
>
>Gupta and Kumar, IEEE transactions on Information Theory, vol IT-46, no.2, pp 388-404, March 2000.
>
>>If the traffic would have been local (i.e. directed to neighbor), then the average percentage traffic per node would be O(1) due to spatial reuse. This is not too bad, since if the network would have been connected on a single Ethernet hub, then the percentage would have been O(1/N). Notice that even with routing overhead, the ad hoc network does better than the Ethernet hub.
>>This result is attainable because when the traffic density increases, the distance between hops decreases and spatial reuse is possible. Unfortunately this is not completely possible with IEEE 802.11 because the CSMA carrier sense level is fixed and prevent close spatial reuse. To obtain theoretical bounds one should need at least a tunable carrier sense level.
>>
>>Philippe
>>
>>A 15:36 27/06/01 -0400, Phillip Neumiller a écrit :
>> >
>> >In the paper found at http://www.pdos.lcs.mit.edu/papers/grid:mobicom01/ "Capacity of Ad Hoc Networks" from MIT labs for CS, the paper concludes that the "key factor" determining whether large ad hoc networks are feasible is the locality of traffic (which results in fewer hops on average between communicators).
>> >Have others found this to be the "key factor" in ad hoc network feasibility?
>> >It would seem to me, that "WHAT" the key factor is would depend somewhat on the network architecture being analyzed and specifically it would depend heavily on the MAC implementation. It seems to me that this paper may have been more appropriately titled "Capacity of Ad Hoc 802.11 Wireless Networks". Is it generally agreed that the 802.11 MAC can adequately represent what the "key scalability factors" are? I think the 802.11 MAC is expedient but not necessarily that useful for generalized analysis. Is there such a thing as a perfect MAC model?, i.e. a MAC that achieves X% efficiency (my guess is its just a circuit switch big enough to connect everyone to everyone else

n(n+1)/2!!!). This would not be very practical in an RF MANET so there must be some happy medium (pun intended)!
>> >
>> >Phil Neumiller
>> >

Subject: Re: Ad Hoc Network Scalability
Date: Thu, 5 Jul 2001 09:57:16 -0500 (CDT)
From: Nitin H Vaidya <vaidya@cs.tamu.edu>
To: mscorson@ix.netcom.com
CC: manet@itd.nrl.navy.mil

Certainly an interesting result.

It might be also useful to point out some limitations though.

Correct me if I am mistaken, but as I recall, the result is only valid when each node is source for one flow at any given time (or more precisely, each node generates packets destined to only one other node in the network). In addition, each node should be destination for only one flow. These constraints, although they make it possible to prove the above result (which is quite interesting), make it difficult to use the result otherwise.

Also, the result requires that each packet take at most 2 hops, which, in turn, requires that each node must meet every other node in the network eventually -- thus, for the result to be valid, it is not enough for the nodes to be mobile, but also that over time each node-pair becomes neighbors (often enough).

Nevertheless, I think the paper makes the interesting point that mobility can increase capacity of the network.

- nitin

Subject: Re: Ad Hoc Network Scalability
Date: Thu, 05 Jul 2001 11:19:12 -0400
From: Chip Elliott <celliott@BBN.COM>
To: Nitin H Vaidya <vaidya@cs.tamu.edu>, mscorson@ix.netcom.com
CC: manet@itd.nrl.navy.mil

Hi Nitin, Hi Scott,

At first blush, it seems like this model could well handle an unlimited number of flows - again, assuming that memory is unbounded and unbounded delay is OK. It also doesn't strictly require all-to-all connectivity, if one has a non-zero probability of copying/moving a packet to any node that one encounters. This would add enough of a random walk element so that a packet could transit a non-fully-connected graph.

-- Chip

Subject: RE: Ad Hoc Network Scalability
Date: Thu, 5 Jul 2001 12:09:34 -0400
From: Phillip Neumiller <PNeumiller@meshnetworks.com>
To: "'M. Scott Corson'" <mscorson@ix.netcom.com>, Joe Macker <macker@itd.nrl.navy.mil>, philippe.jacquet@inria.fr
CC: manet@itd.nrl.navy.mil

Well, this is sort of a "bait-and-switch title". I don't consider this paper's results realistic or all that useful, precisely since it does not put any upper bound on latency.

A "real" system, if being used for anything interactive, will have "real latency" bounds.

A far more interesting paper might analyze maximum bits/Hz/second/user in a MANET (average, and variance (very important)) and show this with a variety of mobility models while increasing the number of mobiles distributed over a fixed area and with fixed mobile density per unit area (area increases with number of mobiles) (alas a much more difficult nut to crack).

Hey I can wish, can't I?

Phil

Subject: Re: Ad Hoc Network Scalability
Date: Thu, 5 Jul 2001 11:19:36 -0500 (CDT)
From: Nitin H Vaidya <vaidya@cs.tamu.edu>
To: celliott@BBN.COM
CC: manet@itd.nrl.navy.mil

hi Chip:

Surely one can generalize to an arbitrary number of flows, but the per-flow throughput will not stay O(1). A simple "proof" is to pretend that each node generates packets destined for a single destination D. So there are n-1 flows with D as the destination. Throughput for each of these flows will be O(1/n), not O(1), since the aggregate rate at which node D can receive is O(1) and there are O(n) flows sharing this.

Similar argument for mobility: It is not necessary for each node-pair to become neighbors over time. So long as we can guarantee O(1) hops, i.e., constant with increasing n, the result will hold.

- nitin

Subject: RE: Ad Hoc Network Scalability
Date: Thu, 5 Jul 2001 13:20:16 -0400
From: "Samir R. Das" <sdas@ececs.uc.edu>
To: "Chip Elliott" <celliott@BBN.COM>, "Nitin H Vaidya" <vaidya@cs.tamu.edu>, <mscorson@ix.netcom.com>
CC: <manet@itd.nrl.navy.mil>

With the risk of digressing a little, I would like to point out that even with a more conventional model, mobility increases capacity. By conventional model I mean a model where we want to relay packets between end points as soon as possible, instead of waiting and buffering for the most opportune moments. This is the model the MANET community is most familiar with.

The intuition here is that mobility randomizes the node positions enough that radio congestion points are now less on average or are more avoidable with an idealized routing protocol (assuming CSMA-based MAC). We have analyzed this effect using simulations (results forthcoming). Also, some published ns-2 based simulation results in the last few years also did show occasional routing performance improvements with mobility!

Samir

Subject: RE: Ad Hoc Network Scalability
Date: Thu, 5 Jul 2001 13:01:08 -0500 (CDT)
From: Nitin H Vaidya <vaidya@cs.tamu.edu>
To: manet@itd.nrl.navy.mil, sdas@ececs.uc.edu

I have not seen your results, but I won't let that stop me -:)

The results for mobility (including those from the Infocom papers cited previously) essentially imply that mobile nodes are likely to see more "favorable environment" every once in a while -- to put it differently, results for the mobile case are averaged over a series of "static" topologies, and hence would look better than some unfavorable static topologies, and worse than others.

For instance, consider the scenario below:

A -- C -- E -- B -- D (topology 1)

Assume that A is sending packets to B, and C is sending packets to D.

Also assume that nodes B and C move such that they periodically swap positions. So the alternative topology here is

A -- B -- E -- C -- D (topology 2)

If we measure performance in presence of mobility, the average is over all topologies, including topology 1 and 2. Clearly, these could look better in the mobile case than in static topology 1, but worse than in static topology 2.

Thus, whether mobility improves "capacity" or not depends on the mobility and communication patterns. Mobility does *not* always improve capacity (i.e., per-session throughput), and might even make it worse, depending on mobility/communication patterns.

So the definition of "capacity" itself is debatable, more so for the mobile case.

- nitin

Subject: RE: Ad Hoc Network Scalability
Date: Thu, 5 Jul 2001 15:48:31 -0400 (EDT)
From: yxiao@cs.wright.edu
To: <manet@itd.nrl.navy.mil>

Is it possible to conduct a mathematical proof to see whether mobility will increase capacity with some assumptions?

Yang

Subject: RE: Ad Hoc Network Scalability
Date: Thu, 5 Jul 2001 19:13:54 -0400
From: Phillip Neumiller <PNeumiller@meshnetworks.com>
To: "'yxiao@cs.wright.edu'" <yxiao@cs.wright.edu>, manet@itd.nrl.navy.mil

I would like to challenge the list to an even simpler problem. Assume a static model, i.e. no mobility, but nodes appear randomly positioned up to some maximum number in a fixed size area (once nodes appear they remain transmitting at the peak they can acheive). Assume CSMA/CA MAC.

I am quite sure that there is some number n, the maximum density, where the throughput per node starts dropping off. After you find n, start moving the mobiles around with various patterns and see if per node throughput goes up or goes down on average. My bet is on down for all known MANET routing algorithms!

To talk about mobility without talking about mobile density seem erroneous to me.

Phil Neumiller
Mesh Networks, Inc.

Subject: Re: Ad Hoc Network Scalability
Date: Sat, 7 Jul 2001 04:13:05 +0200
From: "Philippe Jacquet" <philippe.jacquet@inria.fr>
To: <manet@itd.nrl.navy.mil>

As far as I remember, the key of this result is in the mobility model. The mobility must be uniform in the sense that each node must visit every other node during fairly equal times. This is a very restrictive model and in some extend unrealistic (this is not because you can move that you go equally everywhere). If the mobility model were not uniform then the result would not hold. For example imagine nodes moving only in their vicinity. Phil network model is also another counterexample.

I think the flow model in nodes has a not too much impact excepted that the global statistic on flows must show uniformly distributed sources and uniformly distributed destinations. Which is still not a completely realistic model.

If each node would have an equal number of active flows to every destination in the network, then there would be no need of the two hops trick and one hop transmission would suffice.

Philippe

Subject: Re: Ad Hoc Network Scalability
Date: Sat, 7 Jul 2001 04:30:04 +0200
From: "Philippe Jacquet" <philippe.jacquet@inria.fr>
To: <manet@itd.nrl.navy.mil>

Well, putting aside the problem of CSMA/CA which is specific to 802.11, one would probably come again in the model of Gupta. And we will get the O(1/sqrt(n)), i.e. an overall traffic of O(sqrt(n)). The funny part of this result is that it lead to an unbounded overall total traffic when n increases contrary to a fully wired network.

Philippe

Subject: Evaluating the Scalability of 'On The Move' Routing Protocols
Date: Wed, 16 Jan 2002 09:25:27 -0500
From: "Phil Neumiller" <pneumiller@meshnetworks.com>
To: <manet@itd.nrl.navy.mil>

On demand ad hoc networks do not scale well according to the research at the URL below. Any comments on this work?

http://www.msiac.dmso.mil/journal/wong32.html

Phil

Subject: RE: Evaluating the Scalability of 'On The Move' Routing Protocols
Date: Sun, 20 Jan 2002 12:17:13 -0500
From: Scott Corson <Corson@flarion.com>
To: "'Phil Neumiller'" <pneumiller@meshnetworks.com>, manet@itd.nrl.navy.mil

> On demand ad hoc networks do not scale well according to the research at the
> URL below. Any comments on this work?

For starters...which on-demand protocol was considered? Anyone know?

-Scott

Subject: Re: Evaluating the Scalability of 'On The Move' Routing Protocols
Date: Mon, 21 Jan 2002 11:56:05 -0800
From: Mineo Takai <mineo@cs.ucla.edu>
To: Manish Karir <karir@wam.umd.edu>
CC: Scott Corson <Corson@flarion.com>, manet@itd.nrl.navy.mil

I have been working with Dr. Bagrodia for several years, and have also been using QualNet for my research at UCLA. Although I was not involved in that study, I saw his presentation on this a couple of times, and I remember the study used AODV.

I think the emphasis of this study is the scalability of simulator, rather than the scalability of AODV. While the protocol itself can be modified to support large scale networks, we cannot observe, analyze and improve protocol behaviors in such large networks without an efficient simulation tool. That may be why the article does not explicitly state the protocol used in the study (not to offend a specific protocol by showing rather negative results for its scalability.)

The study explored large parameter space involving over 1,000 simulation runs, and if I recall his presentation, the entire set of experiments completed in less than a week. I do not even try to create 10,000 nodes in ns-2 or OPNET :-)

Mineo

Manish Karir wrote:
>
> It seems like they used QualNet...and from the QualNet page they support:
> AODV Ad hoc On Demand Distance Vector
> BGP Border Gateway Protocol
> DSR... Dynamic Source Routing
>
> (http://www.scalable-networks.com/products/QualNet/networkprotocolmodels.html)
>
> So I'd guess they were studying simulation of AODV(I think...) though why they dont just say that directly is strange...
> Also, has anybody on this list worked with/evaluated QualNet??
> (Is QualNet replacing OPNET as the Army/CECOM favorite?? :)
>
> manish

Subject: Re: performance comparison between Ad Hoc routing protocols
Date: Thu, 07 Feb 2002 09:45:30 -0500
From: Cesar Santivanez <csantiva@bbn.com>
To: ogier@erg.sri.com
CC: manet@itd.nrl.navy.mil

Hi Richard,

ogier@erg.sri.com wrote:

> One problem with total overhead is that it is highly dependent on the amount of data traffic sent, whereas routing control traffic is often fairly independent of this.

That is the whole point .... Routing protocols should be mobility and traffic sensitive ... As the bandwidth and data traffic increase, the `relative cost' of the control overhead decreases... There is an inherent trade off between control overhead and sub-optimal routng cost. Scalability analysis has shown that best peformance can be achieved when these two sources of overhead (or cost) are kept balanced. This means that if we allow data traffic demands to increase, then we should also let the `control overhead' to increase accordingly ...

Now, dynamic adaptation to mobility and traffic may sound far fetch now, but it is something to explore in the future... For the time being, I would suggest to tune protocols to minimize the `total overhead' at the maximum expected traffic load ... This way your protocol will work efficiently when you need this efficiency the most, while under light load -- in most cases -- we may not care about expending extra control overhead bits since we have bandwidth to spare ...

> > There are many instances in my experience where a mechanism that takes more overhead ends up doing better in terms of user metrics.
> I'm not sure if you mean "total overhead" here.

I think Ram was referring to `control overhead' here ...

> But since the min-hop path is not always the best path, it is certainly possible for a protocol to perform better by using longer paths (and thus more total overhead).

Yep.. Specially since `better' may mean less delay, less jitter, etc. What the `total overhead' metric gives you is an indication of the amount of capacity left for data traffic. So, gives you the `potential' for data transmission.

> Full flooding also achieves better reliability by using more total overhead than other flooding mechanisms.

Well, the `total overhead' framework assumes that the network layer provides reliable transmissions, that is, that never gives up until a packet reaches its destination. Thus, for efficient flooding techniques' total overhead's computation you would have to consider all the retransmissions required until getting the data packet to its intended destination. So, the total overhead assumes the `reliable' version (e.g. using network layer ACKs) of the protocols.

> And the following example, in which neither of the two disjoint paths from 1 to 4 uses a min-hop path, shows that sometimes throughput can be increased by using more total overhead:

```
>
>       5-6
>      /  \
>     /    \
> 1 - 2 - 3 - 4
> \    /
>  \  /
>   6-7
>
```

Well, this is not the whole history ... Total overhead relates to remaining capacity, but for ALL the possible flows. You are assuming that only flow 1 --> 4 has traffic to sent, and I agree that in such a particular scenario you'll be better off with load balancing over least interfering paths. But if you consider the maximum combined rates of all the flows (1->6, 1 -> 7, 2 ->6, 2->7, etc.) you will see that the protocol with less total overhead is the one that achieves greater total throughput (granted, there are fairness issues -- specially in the presence of bottleneck links -- so we are not maximazing the minimum flow throughput here). So, if you are sure what traffic pattern you have, to may beat the total overhead design criteria. But if you are assuming that all flows are potentially possible, a better desing criteria would be to minimize the expected total overhead ...

The total overhead metric allow for tractable models to be derived. It is not perfect since it ignores fairness issues (as well as the effect of bottleneck links) by assigning the same cost to all transmissions as oppose to assigning a smaller cost to transmission over `unused' areas of the network (due to the inherent assumption that the network load is high and diverse -- several flows -- and all areas of the network are going to be used).

I'll be more than happy to discuss/explore better metrics that addresses the `total overhead' shortcomings while still allowing for meaningful tractable models to be developed...

Cesar

> > For a more formal treatment of TOTAL OVERHEAD, see
> >
> > Making Link State Routing Scale for Ad Hoc Networks, in Mobihoc 2001 by C. Santivanez et al
> >
> > On the Scalability of Routing for Ad Hoc Networks, to appear in Infocom 2002, by C. Santivanez et al
> >

From: Dmitri Deshun Perkins [mailto:perkin27@cse.msu.edu]
Sent: Tuesday, September 17, 2002 4:36 PM
To: manet@ietf.org
Subject: [manet] scalability in ad hoc networks

Hello:

I have read several papers on routing in ad hoc networks (i.e., manet and sensor). The term scalability is often used. Does the manet group have some specific idea of what is meant by scalable? I have a few questions here.

1. Are we saying an algorithm is scalable depending on its performance (e.g., packet delivery ratio) versus network density? traffic load? control overhead? or some combination of performance measures?
2. What is considered a small, medium, or large network?

These questions are motivated by some simulations done using glomosim. For example, for various network sizes, mobility patterns and traffic loads, protocol A and protocol B achieve very very similar throughput, but protocol A produces significantly more control packets.

3. While, we may conclude that protocol B uses control packet more efficiently (number of packet deliver per control packet), can we say that is more scalable since the performance of both protocols is the same (at least from an external view)? That is, both protocols deliver the same number of packets, but one must work harder to do so, which may impact battery usage.

Dmitri D. Perkins, Assistant Professor
The Center for Advanced Computer Studies
University of Louisiana at Lafayette

Subject: RE: [manet] scalability in ad hoc networks
Date: Tue, 17 Sep 2002 18:02:18 -0400
From: Phillip Neumiller <PNeumiller@MeshNetworks.com>
To: Dmitri Deshun Perkins <perkin27@cse.msu.edu>, manet@ietf.org

Hi Dmitri,

I can not speak for the MANET list, but I hope some others do on this important topic. From a practical perspective, EVERYTHING MATTERS! I don't think it is appropriate to talk about "REAL" ad hoc network scalability without the following in hand (but that's just my opinion and I am often wrong):

o **The traffic model**, i.e. how much peer-to-peer versus how much Internet bound. You can ignore the latter like much of the work so far -OR- you can take it seriously. In my view, MANETs are most useful when they DYNAMICALLY extend the global Internet. Some examples here would be Exponential Poisson, Self Similar or Periodic inter-arrival times (and/or packet lengths) roughly estimating video, voice, and data traffic. Perhaps even more important is the mobile node density / geo-spatial distribution which can severely affect unfairness and congestion in CSMA type MACs like 802.11b. Once you have a variety of traffic models in your hand, you need to determine what are realistic connection models, i.e. what is the mean number of hops for my peers? What is the network diameter that I typically reside in? Are there bottleneck when I gateway through other nodes to the Internet? Does my protocol use hops as its only routing metric and offer me congested routes? What is the mean route convergence time under nominal load? What is the degradation curve for residual bandwidth as network diameter increases (assuming nominally active nodes with 1/2 diameter median hop)?

o **The propagation model**. Is deployment indoors or out? What is the morphology? This interacts with mobility model. Some examples here would be Urban, Suburban, Dense Urban, with varying degrees of Foliage. Don't forget Rayleigh, Ricean, and Log normal shadow fading. Better consider hilly, and flat morphologies as well. Indoors, consider useable data rates with their associated ranges for acceptable BERs, ambient interference, wall, cubicle penetration, etc. How do these devices react to high speed mobility and multi-path and dopler?

o **Mobility model**. How are these devices coming and going (how small are the cells)? Every radio is different, and all of them cause different things to happen to the link layers and TCP/IP. Some example mobility models may include Random, Markovian, Pedestrian, column, linear, urban, exponential correlated. Random waypoint sardeen testing is good too.

If you want an anti-septic definition see the Kumar-Gupta paper or the MIT results and many others. I find these definitions of scalability only oflimited use because they tend to bound scalabilityasymptotically but mean almost nothing in practical scale networks of 10s of nodes. In practical ad hoc networks you will likely run into one of the many above factors before you run into asymptotic scalability of your routing protocols.

NOTE: Many of the above issues took MANY years to resolve for cellular networks, and it is un-realistic to assume they will be resolved quickly for ad hoc networks. Errors propagate in nasty ways in ad hoc networks. Hopping over three 10E-02 BER links in a row becomes a (.9) ^ 3 = 72% reliable. This adds up quickly all over your network. Many routing algorithms work best if links are assumed bi-directional, and to ensure this reduces cell size and range.

NOTE: It is very important to use an on-demand protocol (reactive) and everybody seems to agree to that on the MANET list as far as I tell.

NOTE: The MAC can have a dramatic affect on MANET performance in many practical situations.

NOTE: Nobody in the IETF wants to work on L2 triggers to foster better cross-layer interaction between RF L2s and the IP stack. (a pet peeve of mine that is likely to remain for the foreseeable future :-)

NOTE: If smart antenna technology could be made in a tiny package it would solve the lion share of problems that plauge MANET scalability!!! No more hidden nodes, no more exposed nodes, incredible data rates at long range because of improved SNR, less self interference, etc. etc. etc.

NOTE: Key distribution is VERY tricky in ad hoc networks and a research topic. Security in general for ad hoc networks is a mystery as far as key and/or certificate management scalability goes.

I hope this helps frame some aspects of the scalability problem in a practical way. Much of the work to date has been theoretical, which OK, but I sure would like to see some more practical results. The IEEE has published a few papers with test bed results, but often a large number of the above factors were not part of the controlled experiments. Let the experimental stage of MANET begin! Gentlemen, turn off your simulators!!!!

Thanks and best regards,

Phil Neumiller

Subject: Re: [manet] scalability in ad hoc networks
Date: Wed, 18 Sep 2002 22:00:55 -0400
From: Cesar Santivanez <csantiva@bbn.com>
To: Dmitri Deshun Perkins <perkin27@cse.msu.edu>
CC: manet@ietf.org

Dmitri,

We were also looking at the issue of scalability for MANETs and found that there were not clear consensus of what it meant for a routing protocol to be deemed scalable. There was a confusion about network scalability (what the network can support) and routing protocol scalability (what the routing protocol can handle provided that the network can).

For example, if we consider the class of `power controlled' networks where the node degree is bounded and with a uniformly distributed traffic pattern, we may see that as we increase the size of the network the traffic requirements become unbearable. This is due to the traffic increasing much faster than the network rate (sum of all possible simultaneous transmissions). Thus, this class of network does not scale w.r.t. network size. So, if the network does not scale w.r.t. network size, what is the meaning of a routing prrotocol being scalable???

In our INFOCOM paper (reference below), we presented our position on this topic, stating that a routing protocol is scalable (w.r.t. a parameter X) if -- as the parameter X increases -- the routing protocol does not significantly degrades network performance. Simply speaking, if the network can support thousands of nodes for a given traffic load, then the routing protocols (to be considered scalable) should not break when run over that network of thousands of nodes with that traffic load. So, basically, routing protocol scalability means matching (or improving) the network scalability properties.

Respect to your point (3), respect comparing routing protocols scalability, the answer is not so simple. You need to extrapolate the results to what will happen when you increase size, mobility, etc. Measuring the control packets generated for a routing protocol does not provide enough information to produce this extrapolation since there are other factor as for example route sub-optimality that may become more relevant as you increase traffic and network size. For example, the routing protocol that produces less control overhead may be forming longer paths than necessary, which may not be an issue at your current traffic rate, but as the traffic rate increases the extra hops may be comparable (or greater than) the control overhead.

For this reason, we prefer tackle this scalability issue from a theoretical point. We develop a framework for studying scalability in ad hoc networks and applied this framework to the study of several representative protocols in the literature. The class of networks we studied were bounded-degree with uniformly distributed traffic, but the methodology can be extended to other type of MANETs.

Hope this helps

Cesar

References:

C. Santivanez, B. McDonald, I. Stavrakakis, and R. Ramanathan, "On the Scalability of Ad Hoc Routing Protocols," Proceedings of IEEE INFOCOM'02, New York, June, 2002. Available at : http://www.ir.bbn.com/documents/articles/infocom07.pdf

C. Santivanez, R. Ramanathan, and I. Stavrakakis, "Making Link-State Routing Scale for Ad Hoc Networks," Proceedings the 2001 ACM International Symposium on Mobile Ad Hoc Networking & Computing, MobiHOC'2001, Long Beach, California, October 4-5, 2001. Available at : http://www.ir.bbn.com/documents/articles/mobihoc01v4.ps