Scientific Background of mesh:ine

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In this paper we describe the scientific background of mesh:ine and the technology being developed at as mesh:tech. The academic work has been done at the Distributed Embedded Systems (DES) group, Freie Universität Berlin, and the Communication and Networked Systems (ComSys) group, University of Münster.

Prof. Günes was the head of the DES group from 08/2007 to 04/2014, since 05/2014 he leads ComSys.

1 ORIGIN OF WIRELESS MULTI-HOP NETWORKS

A **wireless multi-hop network** (WMHN) is a computer network consisting of only wireless links [1]. In a WMHN, two nodes – denoted as source and destination – can communicate with each other in two ways. First, if the source and destination nodes are mutually in their communication range, the both nodes can communicate directly. Second, the source and destination nodes are distant to each other and cannot communicate directly, in this case other nodes – intermediate nodes – have to forward the data packets from the source node until they reach the destination node and vice versa. The latter case is called multi-hop communication [1].

All nodes in the WMHN are of the same class, thus we do not distinguish between hosts, i.e., end-devices, and network devices. The functionality of the »network« like routing is realized by all participating nodes together [1].

We denote a WMHN as a **wireless mesh network** (WMN) if the nodes are static and do not move. If the nodes in a WMHN are mobile and can move around we denote it as a **mobile ad hoc network** (MANET). The challenges of the both classes of WMHNs are mainly the same, with some differences particularly regarding the routing in a MANET.

WMHNs are not new, but have been studied and developed since the 1970s [2]. Most realizations of WMHNs are based on special hardware, since the requirements were not fulfilled with legacy hardware.

The requirements for WMHNs can be classified as follows:

Hardware

- Wireless interface with high speed data rate.
- Strong CPU for the processing of data packets.
- Memory capacity to store data packets temporarily.

Software / Algorithm / Protocol

- Addressing: the nodes in the network need to be addressed, i.e., to identify them.
- Routing: a route between the source and destination node has to be found and maintained during the communication.
- Management: information about the nodes, their status, and additionally neighborhood information need to be collected and distributed in the network.

With the success of smartphones, a hardware platform, which meets most of the aforementioned requirements for WMHNs, particularly the hardware requirements, is available as a mass product.

However, most of the software requirements are not supported by the respective operating systems (e.g., Android OS, iOS). Furthermore, the operating systems of smartphones are optimized for the usage with cellular networks.

In respect to the usage of smartphones, as nodes in the WMHN, the realized network can be classified between a classical WMN and a MANET. The distinguishing property between both networks is the mobility of the nodes. In this discussion, we assume a low mobility of the devices, which results by people carrying the smartphones and walking around at a festival or similar. From this point of view, the difference between a WMN and MANET can be neglected. Therefore, we will refer only to WMN in the remainder of this text.

2 STATE OF THE ART OF STUDYING WIRELESS MESH NETWORKS

Wireless mesh networks can be studied with the following approaches.

- Formal analysis: This approach is based on mathematical modeling of the wireless mesh network and results in a set of formulae, that describe a certain characteristic of the WMN. This approach does not include any real system software like an operating system, routing etc. Thus, only asymptotic performance limits can be derived.
- Simulation: In a simulation environment a model of the wireless mesh network is developed. There are two different kinds of simulation techniques. Packet level simulation and simulation on abstractions of the wireless mesh network (e.g., a graph). This approach does not include real system software like an operating system, and the drivers of a wireless network interface card. However, on an algorithmic level address distribution and routing can be studied reliably. What is particularly missing is the physical transmission of wireless signals, which cannot be simulated in an acceptable way. The advantage of simulation is that it enables the study of the scalability of algorithms and protocols, i.e., networks with 10.000 to 100.000 nodes can be studied.
- Virtualization: In a virtualization environment a virtual computer is running a real operating system and system software. By this, a scalable number of virtual computers (up to 10.000) with system software can be created. If these computers are equipped with a virtual wireless network interface a virtual wireless mesh network can be created. With this approach all components of the wireless mesh network consist of real system software (e.g., operating system, routing, address distribution etc.), but only the wireless link is simulated. This approach eases the development of distributed algorithms and protocols for WMN and accelerates the debugging of the software. Furthermore, special designed network topologies support the testing and performance evaluation of protocols on the algorithmic level.
- Testbed: A testbed is a real-world laboratory based on real hardware and software consisting of computers, operating system, software for addressing, routing, and management of the wireless mesh network. Experiments performed in a testbed are very close to real-world applications of a wireless mesh network, even the wireless transmissions. Thus, a testbed supports the derivation of performance metrics of a WMN as close to a real deployed network.

Figure 1 depicts the characteristics of the different environments and Figure 2 shows a comparison of the different environments regarding the ISO/OSI reference model with respect to transferability of the results into real-world network deployments.

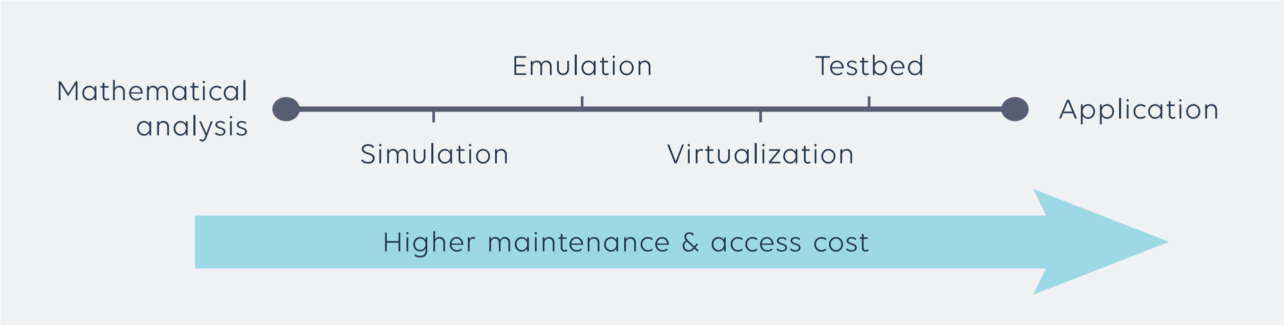

Figure 1: Environments to study a wireless mesh network.

Layer (ISO/OSI)	Enviroments				
	Analysis	**Simulation**	**Emulation**	**Virtualization**	**Testbed**
Application	—	low	high	high	high
Transport	—	low/high	middle	high	high
Network	—	high	middle	high	high
Data Link	—	middle	middle	middle	high
Physical	—	high/low	—	—	high
Model vs. System Software	Model Formulae	Model Software	System Software	System Software	System Software & Hardware

Figure 2: Comparison of study environments for WMNs. Degree of transferability of results to real-world network deployments. The last row summarizes the characteristic of the environment in respect to system software.

3 THE DES APPROACH AND DES-SERT – A HOLISTIC AND THOROUGH APPROACH TO STUDY WIRELESS MESH NETWORKS

The DES approach combines simulation, virtualization, and the testbed approaches in a scientifically sound way. Thus, a WMN can be studied on different granularity levels, various scales, and in terms of varying performance metrics. At the same time the focus is kept on a holistic, but system based study.

Figure 3 depicts the scientific and experimental life cycle supported and implemented by the DES approach and the tools, which implement them [7, 8].

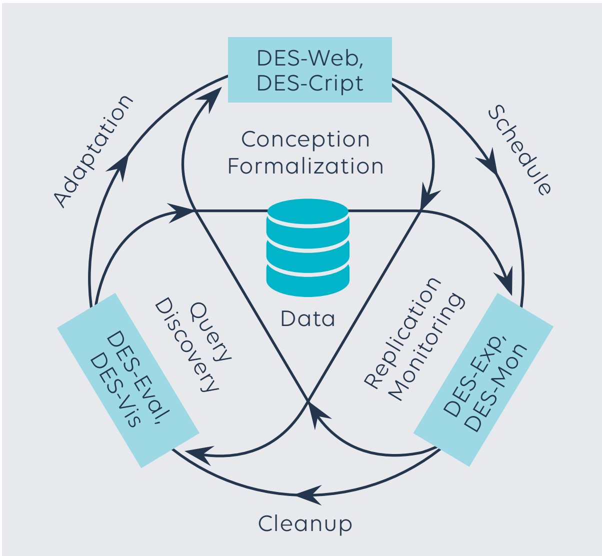

Figure 3: Experiment and scientific life-cycle realized in the DES approach to study and develop system-level WMHN algorithms and protocols. The approach is implemented in form of modular software tools like. DES-Web, DES-Cript, DES-Exp, DES-Mon, DES-Eval, and DES-Vis. By this replicated and repeatable network experiments can be run, which fulfill scientific requirements for experimentation and analysis.

3.1 DES-SERT

DES-SERT (DES–Simple and Extensible Routing-Framework for Testbeds) is a software framework that eases and simplifies the implementation of routing protocols for wireless multi-hop networks [6]. The goal of DES-SERT was to enable the researcher to study and compare routing algorithms on the algorithmic level by standardizing the implementation of services like the routing table, the sending and receiving of packets, and the access to the operating system services. Figure 4 shows the architecture of DES-SERT.

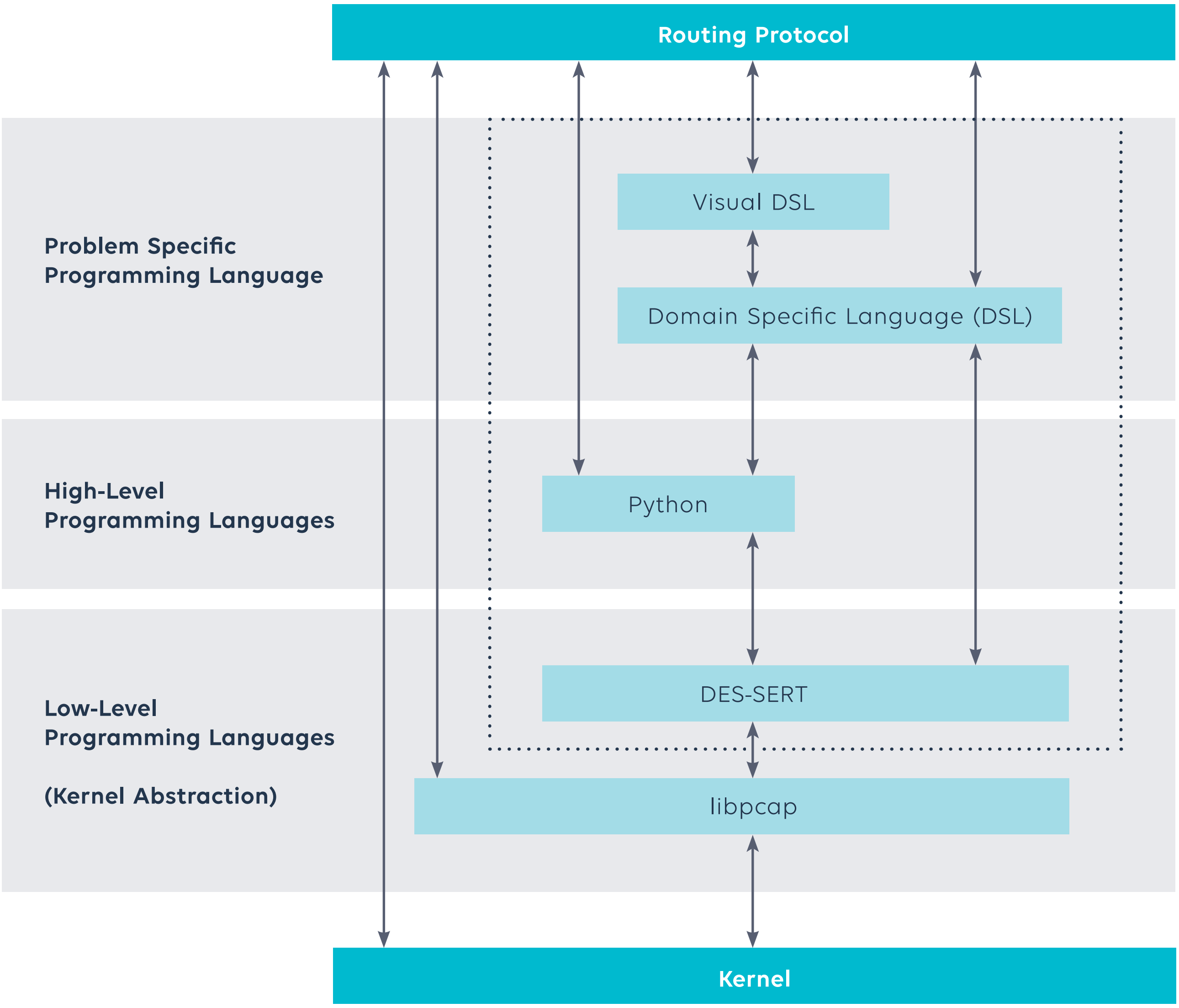

Figure 4: DES-SERT Routing Framework.

The following routing protocols are implemented in DES-SERT and studied in the academic environment:

- AODV
- ARA
- BATMAN
- DSR
- Gossip routing (9 variants)
- OLSR

4 WHAT DID WE LEARN ?

In this section we give an excerpt from the rigorous academic background of mesh:ine.

4.1 NUMBER OF NEIGHBORS

Figure 4 depicts the number of neighbors for each node in the DES-Testbed. The figure shows the mean, and the confidence interval of the number of neighbors. The number of neighbors varies from 4 to over 50 nodes. Thus, the assumption – usually taken in simulative studies – of a small fixed number of neighbors in a realistic WMN does not hold. This variation provides particular advantages in reality, since a huge number of redundancy is inherently available in the network. Additionally, this has also an impact on the implementation of the address distribution, the routing protocol, particularly the realization of the routing table, and the service discovery.

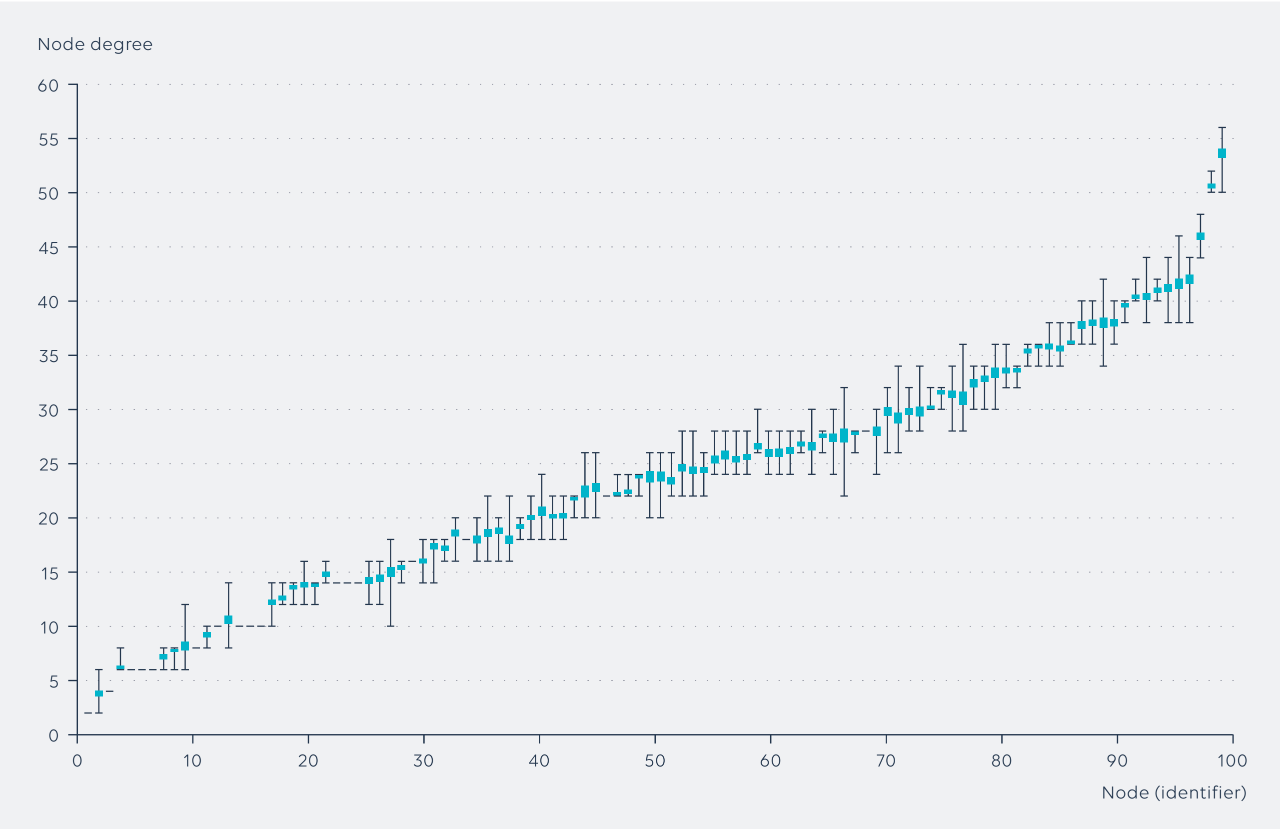

Figure 5: Node degree in the DES-Testbed.

4.2 END-TO-END PATH LENGTH

Figure 6 depicts the end-to-end path length from each node to all other nodes in the DES-Testbed. The figure depicts the mean and the confidence interval of the end-to-end path length. Although, the network is deployed over 4 buildings, the number of hops between a source and destination node is limited by 6 hops. Thus, the number of forward-transmissions of a data packet from the source to the destination node is limited.

This has a great impact for real WMN deployments, since the routing protocol can be optimized to a small number of forwarding operations. This will result in better performance (i.e., throughput and delay) and at the same time in lower packet loss [9].

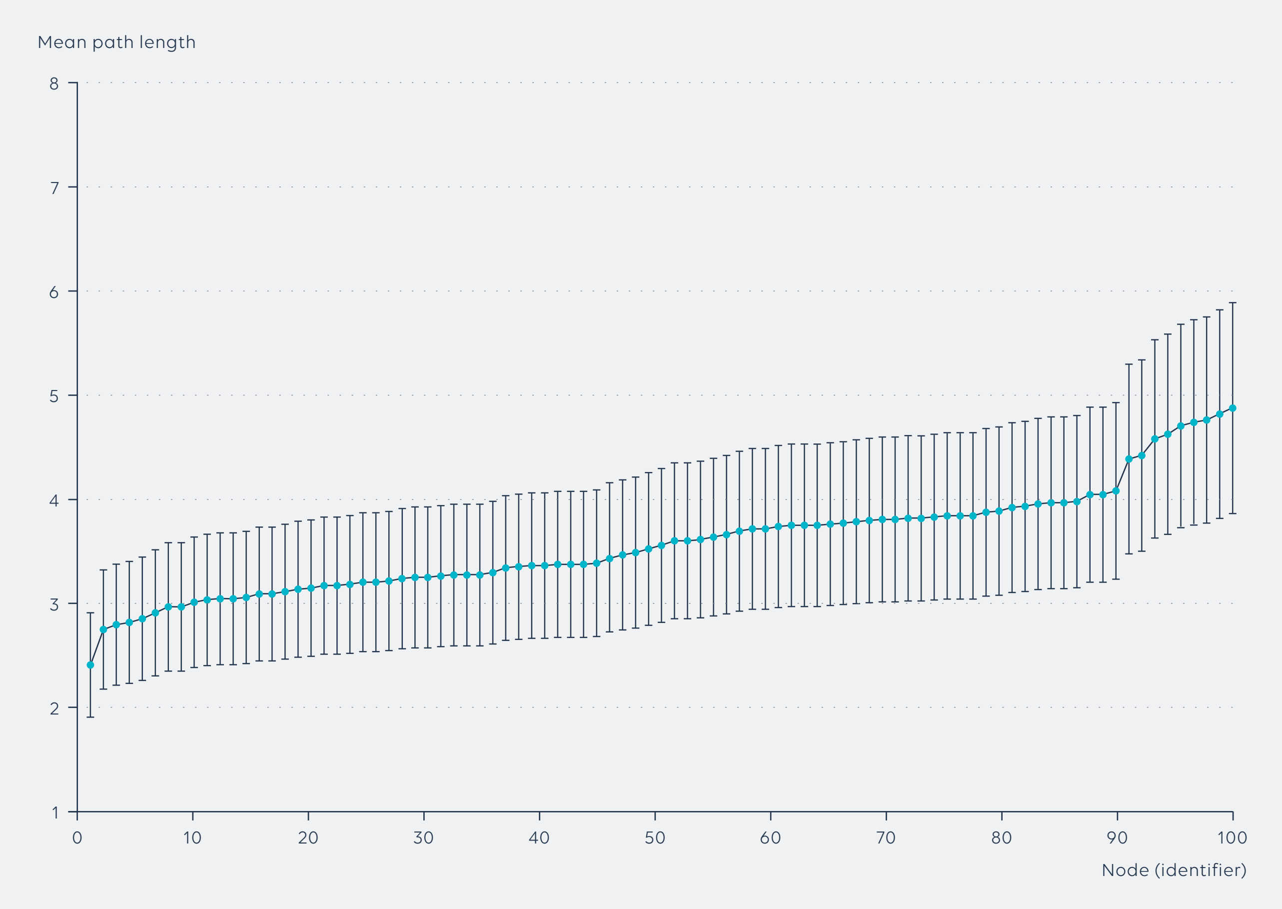

Figure 6: End-to-End Path Length in the DES-Testbed.

4.3 THE NEIGHBORHOOD OF A NODE IS DYNAMIC

Figure 7 shows the development of the neighborhood of the DES-Testbed depending on the number of nodes and the used packet length to discover the neighborhood. By this, two insights are gained for real WMN deployments. First, the total number of nodes in the network has a positive impact to the neighborhood, since the density of the network is increased. This leads to higher number of nodes, i.e., higher redundancy, which are available and can be used for packet forwarding. Second, the packet length used to discover the environment has also an impact. Please note, that this insight is directly coupled to the wireless technology used on the lower layer, i.e., MAC and PHY protocols are important and have an influence on the results. Small discovery packets are more successful in large networks and lead to the discovery of more neighbors.

In the comparison of the results for packet size 128 and 1408 byte the impact is clearly seen. This insight means for real WMN deployments that the optimal packet size for different networks services may vary and has to be used.

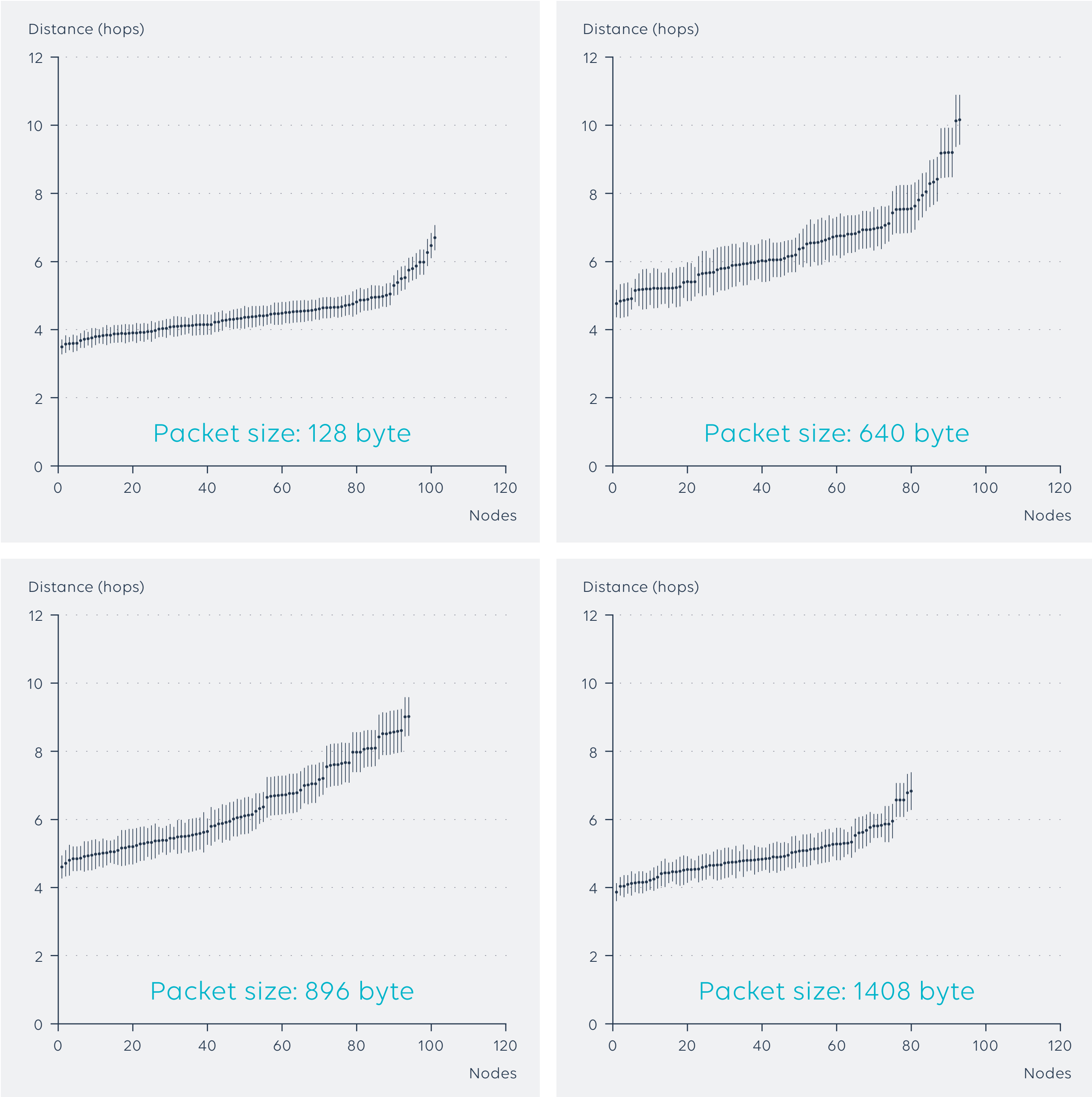

Figure 7: Neighborhood of DES-Nodes as a function of packet length.

5 DISCUSSION AND OUTLOOK

In this paper we have sketched the academic background of mesh:ine. For this, we have given a brief historical overview of wireless mesh networks, the hard- and software requirements, and the DES approach to study and develop system software for wireless mesh networks. The DES approach is realized as a number of software for computer aided tools to develop and run experiments on a deployment level testbed. By this, the distributed nature of the wireless mesh network is kept and at the same time the operation and inter-dependency of the algorithms and protocols can be traced and analyzed.

Additionally, a brief summary from the rigorous and vast research on this topic were given at selected examples which influence systems software performance at various levels of the protocol stack. The given experimental results have an impact on the design of the routing protocol, the need for addressing, the number of hops between source and destination pairs, the design of auxiliary protocols like neighborhood discovery, route discovery and route maintenance, and the achievement of quality of service agreements.

6 REFERENCES

An excerpt of academic papers which back up mesh:tech is given here. For more information and additional publications, we refer the reader to:

http://www.des-testbed.net
http://www.uni-muenster.de/Comsys/en/publications/index.shtml

[1] Mesut Günes: Lecture »Embedded Internet und Internet of Things«, SS 2014, http://www.uni-muenster.de/Comsys/en/teaching/ss2014/vorlesung_iot.html

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