

# Supply and demand in Wireless Sensor Network Testbeds

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**Abstract**—Majority of researchers use simulation tools instead of actual sensor network deployments to validate their theories, yet the tool intended to facilitate the transition from simulations to deployments already exists in form of testbeds. In this abstract, we put forward 3 claims related to supply and demand in Wireless Sensor Network testbeds, by analyzing the results of systematic reviews about actual sensor network deployments and testbed facilities. We found that testbed facilities should provide more functionality related to TRL 6 and TRL7 and focus more on providing simple low power embedded devices for users to promote the usage of testbed facilities.

**Keywords**—wireless sensor networks, testbed facilities, testbeds, internet of things, iot, wsn, systematic review

## I. INTRODUCTION

The research community has been working on sensor networks for more than seven decades [1]. The research output related to sensor networks really took off in the 1980s when DARPA started its distributed sensor network program [2], and now, with the advent of Wireless Sensor Networks (WSN) and Internet of Things (IoT), more than a million research articles on sensor networks have been published, with this number growing every day. Yet majority of researchers still use simulation tools to validate their theories [3] there must be a reason for the under-usage of actual sensor network deployment and testbed facilities. To understand this reason we examined two separate systematic reviews on: (i) actual sensor network deployments and (ii) available testbed facilities, with the aim of understanding what might be the possible bottlenecks of achieving the full potential of available testbed facilities in order to facilitate research validation by using an actual sensor network deployment.

## II. TESTBEDS IN SENSOR NETWORK DEPLOYMENTS

In the data set published by Judvaitis et al. [4] more than 15 000 unique research articles were evaluated resulting in 3059 articles describing sensor network deployments in a five year period from 2013 to 2017, they were identified and codified extracting 12 metrics about each of the sensor network deployments. The resulting systematic review by Judvaitis et al. [5] informed that the usage of sensor network testbed facilities has not changed significantly over the years, as shown in the Table I. But looking at the rolling average for a three year period 2013 - 2015 (16.40% per year), 2014 - 2016

(15.06% per year) and 2015 - 2017 (14.83% per year), the usage of testbed facilities is slowly declining.

Year	Deployments using testbed facility	Deployments total
2013	103(16.6%)	619
2014	104(16.9%)	616
2015	95(15.7%)	606
2016	75(12.6%)	596
2017	101(16.2%)	622
Total	478(15.63%)	3059

TABLE I

USAGE OF TESTBED FACILITIES IN ACTUAL SENSOR NETWORK DEPLOYMENTS BY YEAR

Judvaitis et al. [5] also notes that the most deployments used testbed facility when the deployment is targeting TRL5 (38.9%), this is because TRL5 means "technology validated in relevant environment" as defined by the European Commission [6] and testbed facility can be regarded as a relevant environment, because usually it is not located directly at the lab. Table II shows the sensor deployment technology readiness level for the deployments using testbed facility.

TRL	Deployments using testbed facility	Deployments total
TRL3	3(2.9%)	103
TRL4	26(3.8%)	682
TRL5	346(38.9%)	888
TRL6	54(11.3%)	479
TRL7	44(5.3%)	826
TRL8	5(6.2%)	81
Total	478(15.63%)	3059

TABLE II

USAGE OF TESTBED FACILITIES IN ACTUAL SENSOR NETWORK DEPLOYMENTS BY TECHNOLOGY READINESS LEVEL

The data about sensor network deployment distribution by used sensor node indicates that in the common case (77.61%) sensor network deployments are based on simple devices, in some cases (13.60%) more sophisticated devices are involved in the role of base stations. Only small amount of deployments (7.39%) are completely based on advanced devices.

## III. AVAILABLE WSN TESTBED FACILITIES

In the data set published by Judvaitis et al. [7] more than 350 unique research articles for a 10 year period of 2011 to 2021 were evaluated resulting in 45 articles describing 32 testbed facilities, they were codified extracting 15 metrics about each of the testbed facilities. The resulting systematic

review by Judvaitis et al. [8](unpublished) informs that they identified 60 deployment locations (a single testbed facility can have multiple deployments), of which 45 (75%) were located in an office environment corresponding to TRL5 and 14 (23%) deployments were located outdoors, typically a TRL6, with a single deployment being in a materials handling facility. Judvaitis et al. [8](unpublished) also reveals that of the available Devices Under Test (sensor nodes available for the user to experiment on) across the 32 testbed facilities there are a total of 5253 (56.8%) custom made sensor nodes, 2152 (23.3%) low performance embedded devices, 1662 (18.0%) high performance embedded devices, 124 (1.3%) mobile devices and 57 (0.6%) single board computers. Authors also noted that only 9 of the identified testbed facilities were available online.

#### IV. DISCUSSION

The combination of the results of systematic reviews about sensor network deployments and wireless sensor network testbed facilities gives us an opportunity to examine both the supply and demand in the wireless sensor network domain related to the testbed facilities. As a result we are putting forward 3 claims.

**Claim I - there is a demand for flexible deployment options, but not enough supply.** Comparing the provided deployment locations of testbed facilities with the total amount of sensor network deployments it is visible that TRL5 is the most popular level (38.9%) for sensor network deployment taking advantage of testbed facilities and they tend to provide TRL5 comparable deployment locations the most (75%). Since TRL4 and below as well as TR8 and above is not really the target for testbed facilities we need to examine what is necessary from testbed facilities to foster usage at TRL6 and TRL7. As TRL7 means "system prototype demonstrated in operational environment" as defined by the European Commission [6], the testbed facility needs to support deployments in any location to support this level. This can be achieved by providing flexible deployment options allowing the testbed workstations to be deployed independently with only minimal, e.g. power and internet connectivity, or no requirements from surrounding infrastructure.

**Claim II - the demand for low performance embedded devices is high, but supply is lacking.** According to the testbed facility review only 23% of available Devices Under Test are low performance embedded devices, they are comparable to the simple devices described in the sensor network deployment review and are used exclusively in more 77% of all deployments and for 13.6% only base station was not low power embedded device. This gap needs to be minimized in order to facilitate the usage of wireless sensor network testbed facilities.

**Claim III - there is a large supply of custom devices, but not enough demand.** When comparing the provided Devices Under Test by the testbed facilities and sensor nodes used in actual sensor network deployments, it is visible that more than 56% of provided nodes are custom made, meaning that they

can not be purchased off the shelf. Unfortunately the sensor network deployment analysis does not provide information about the usage of custom devices. But one could argue that very few are willing to experiment on custom hardware provided by the third party because the custom platform: (i) may require steep learning curve, (ii) is unlikely to be mature and bug free, (iii) has very limited support, and (iv) is difficult to scale beyond the testbed facility.

#### V. CONCLUSIONS

In this abstract we are using the results two separate systematic reviews in closely related domains, sensor network deployments and testbed facilities, to examine the supply and demand in wireless sensor networks related to the usage of testbed facilities. We provide brief introduction in the relevant result of the systematic reviews and put forward 3 claims about the current status of testbed facilities. We gave suggestions related to functionality of testbed facilities in order to increase the usage in future sensor network deployments and facilitate faster progression through TRL levels.

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