

Functional scheme of the environment monitoring systems architecture design

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Abstract — Design process of the architecture of environment monitoring systems (EMS) gives rise to problems of selection and location of system components: monitoring stations, transit nodes, sensors, information collection centers, antennas, power supply systems, telecommunication and other equipment. Several examples of EMS are: wireless sensor networks, flying sensor networks, lightning discharges location systems, high-resolution GLONASS/GPS receivers networks, geomagnetic field measurement networks, hybrid systems of forecast and search of strong earthquake precursors, ionosphere monitoring systems etc. The main problem of architecture synthesis of the EMS is formation of a set of solutions on locating system components and multicriterial evaluation of each of the solutions. The functional module of the EMS architecture synthesis is an important component of special-purpose support systems of EMS design. In the present work we consider some problems of environment monitoring systems synthesis and propose a simplified functional scheme of the EMS synthesis.

Keywords — environment monitoring, systems synthesis, network graph, system architecture, wireless networks.

I. INTRODUCTION

Environmental Monitoring (EM) is a process through which we monitor the changes that occur in the environment. Looking at the current scenario of how rapidly the environment is changing due to changes that have occurred after the presence of humans on this earth is drastic. We need to monitor the changes in order to protect the environment from degrading even further. These systems monitor the following parameters i.e. air, soil, water, weather, climate and etc. Typical applications, in addition to purely environmental science purposes, include the protection of water supplies, radioactive waste treatment, air pollution monitoring, natural resource protection, weather forecasting and enumeration and monitoring of species [1]. Environmental Monitoring determines the changes of the environment by analyzing samples from the environment. These systems consist of data monitoring nodes, a data base station and a remote monitoring system. As the sensors have to operate in adverse conditions, they need to be robust and adaptable in nature. In the following paragraphs describe the major *Environment Monitoring Systems (EMS)*.

II. EXAMPLES OF THE ENVIRONMENT MONITORING SYSTEMS

A. Air Environmental Monitoring System

The air that we breathe nowadays contains a lot of unwanted harmful unwanted particles as compared to air that was around people a century ago. The pollutants in the air around us have grown drastically due to industrialization. For example, we can build wireless sensor network (WSN) for air pollutant monitoring with *Wasp mote* [2] and the gases sensor board. The gases sensor board is able to monitor the city pollution gases such as carbon dioxide, emissions from farms and hatcheries like methane, industrial gases, gases from forest fires and etc.

B. Agricultural and Field Environmental Monitoring System

The agricultural crop yields depend on environmental conditions, and changes that may occur in these conditions can alter the crop output. It is necessary that farmers monitor changes occurring in their land by themselves. The major parameters that these sensors have to monitor are the nutrients, minerals, fertility, pH levels, carbon status and etc. For example, the *Wasp mote Agricultural Board* [3] is able to monitor 14 essential environmental parameters in a wireless sensor network. This system is able to monitor parameters such as soil temperature, soil moisture, leaf wetness, fruit/stem/trunk diameter, etc.

C. Water Environmental Monitoring System

A large number of nodes are placed in water bodies and each node can monitor different parameters such as pH, amount of dissolved oxygen, electrical conductivity rate, temperature and etc. These nodes are capable of gathering the data and sending the data to the base station which is then sent to the remote monitoring for further analysis. The most important characteristics of the *Water Environment Monitoring System* are large network capacity, flexible disposition, low power consumption, low cost, and minor influence on the natural environment. For example, *Wasp mote Smart Water Platform* [4] is a commercially available water monitoring device. The data is available in real time and can be transmitted to the cloud wirelessly. The flexibility of this device is an important characteristic. It can be used for any of

the following applications; drinking water quality control, agricultural water monitoring, swimming pools,

D. Soil Environmental Monitoring System

There are many methods used to assess soil. The most important assessment is the soil's fertility as we need fertile soil to grow crops and survive. Soil and sediments may become polluted in a number of ways (disposal of industrial and domestic solid wastes, wet and dry deposition from the atmosphere and infiltration by contaminated waters) and the main pollution hazards on land. These include harmful substances in soil or plants and subsequently into food supply; substances washed from land and pollute water supplies; contaminants may be suspended and subsequently inhaled; Land may be potentially dangerous or unsuitable for future use due soil erosion; ecological system may be damaged with consequent loss to conservation and amenity [5].

E. Weather and Climate Environmental Monitoring System

These systems are used to determine the weather status of a particular area. They are able to predict the weather for the next couple of days based on the data collected by the sensors. Digital Image Processing is used to understand the weather patterns from space. These monitor the weather from space and then transmit it back to earth via satellites. The weather sensors are capable of measuring the pressure, precipitation, temperature and etc.

F. The Earth's magnetic field Monitoring System

There are a number of the magnetic station networks of different ranks for various fundamental and applied scientific tasks, which works under common standards and projects.

Global networks are the joint of the magnetic observatories, where total magnetic field are observed continuously during long time. In general, these observatories belong to various countries and institutes and, if possible, are uniformly distributed over the globe. The data obtained from these networks have fundamental significance and give the experimental basis for researches both in retrospective and perspective senses. The example of such network is magnetic observatories of IAGA, formed after International Geophysical Year in the late fifties. After the changing of analogue magnetometers to digital ones the IAGA networks was transformed to modern network INTERMAGNET [6]. Magnetic observatory gets the status of INTERMAGNET observatory (IMO) if it conforms the high standards (sensitivity is 0.1 nT, absolute accuracy of component of magnetic total field vector is better than 1-5 nT, the rate of measurements is 1 Hz, the sending of data to INTERMAGNET database centers in according to data status, etc. [7]. At present about 140 magnetic observatories are IMOs, including 9 IMOs in Russia and 3 IMOs in IKIR FEB RAS [8]. Main task of IMOs is longtime observations of absolute values of the Earth's magnetic field for study of main field of the Earth. Of course, specifications of IMOs data allow to solve other tasks, for example, in magnetospheric physics.

The next example of a global magnetic network is magnetic observations at repeat stations (RS). The goal of such observations is estimation of spatial distribution of the slow changes of the magnetic field with spatial resolution better than from magnetic observatories. The Repeat Station activities are the observations of total field at fixed points at Earth's surface. The distance between RS points is order smaller than distance between magnetic observatories. The repetition of the observations is from one to five years [9]. The RS observations use common standards and obtained data are absolute values of magnetic field, related to some epoch.

The regional networks, in general, are national and created by separate institutes or department. They can be a spatially isolated part of the global networks and are directed to specific regional tasks. Obtained data are not limited by international standards. Good example of such network is MAGDAS Project of Environment Research Center (SERC, Kyushu University, Japan), which is evolution of projects "210° Magnetic Meridian" and "Circum-pacific Magnetometer Network" [10]. The fluxgate magnetometers MAGDAS measure the variations of three components of geomagnetic field with rate of 1 Hz and resolution up to 0.1 nT. These systems were installed at a lot of stations and observatories near magnetic meridian 210°, along the coast of Pacific and magnetic equator. The several MAGDAS system were installed at observatories of IKIR FEB RAS and IKFIA SB RAS, Russia. The main goals of project are investigations of quick process in the ionosphere-magnetosphere.

The network of four geophysical observatories of IKIR FEB RAS covers the Far East region of Russia over wide range of the latitudes from southern border to coast of Arctic Ocean (see Fig. 1). The regular monitoring of magnetic field are performed at these observatories, including in according to INTERMAGNET standards at Khabarovsk KHB, Magadan MGD and Paratunka PET (Kamchatka). The observatories are equipped by modern digital magnetometers for measurements with rate of 1 Hz and sensitivity up to 0.1 nT. The absolute magnetic observations for control of baselines of magnetic variometers are performed and the total intensity vector values are obtained with times up to decade. These observatories joint the various geophysical measurements, such as ionospheric sounding, atmospheric electricity, cosmic ray intensity etc.

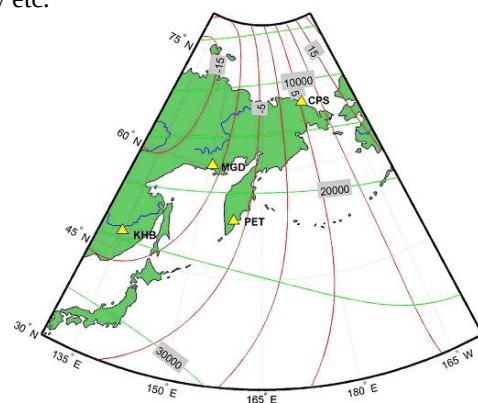


Figure 1. The geophysical observatories of IKIR FEB RAS, jointed to the Far East regional network

The local networks has the typical scales up to first hundreds kilometers. They are created for specific tasks, are equipped by standard measurement systems and, in general, are recorded only geomagnetic variations. The examples of such networks are projects IMAGE in Scandinavia [11] or MAGIC in Greenland [12]. Results of measurements by these networks are used for studies of high-latitude ionosphere and magnetosphere.

We can create fixed magnetic station networks if:

- 1) there is task to get the data from spaced points at the same time;
- 2) the devices are need to special conditions, such as non-magnetic huts, stable pillars, stable temperature etc;
- 3) the time required for transportation and setup of instruments, exceeds the characteristic times of variations of the magnetic field;
- 4) transport costs exceed the costs of the maintenance of the measurements on the stationary points.

We can't create fixed magnetic station networks (and need to create "dynamic" magnetic networks) if:

- 1) it can not have the required number of devices because of their cost or uniqueness (there are only single devices);
- 2) the network includes a very large number of points on which it is impossible to provide adequate infrastructure;
- 3) main interest are only the spatial variations of the magnetic field, and the time variations can be effectively excluded or they are insignificant;
- 4) the cost of equipment and maintenance of the infrastructure of stationary network higher than the costs of organizing temporary stations.

Some tasks for "dynamic" magnetic networks creation:

- 1) the uniformity of points over interested area; if there are a priori information about filed distribution the network can be more dense over area with high field variability and more rare over area with uniform field;
- 2) the specific distance between network points are depended on the requires of the structure description of the field (for example, the point distance during the researches of the main filed of the Earth is compared with extension of the main magnetic anomalies and it can reach to hundreds-thousands of kilometers, the point distances are from a few to tens of kilometers during magnetic survey of anomalies at upper crust and are about meters during micro survey);
- 3) the ability to have the reliable supporting information. For example, during the observations at repeat stations the reduction of geomagnetic variations from magnetic observatories to repeat station area are needed. These is hard scientific and applied task.

Some technical aspects of "dynamic" magnetic networks:

- 1) the duration of autonomous work (power supply, capacity of recorder, the possibility of preliminary processing of measurement results, staff, etc.);
- 2) the possibility to transportation the equipment to field station;
- 3) the possibility to provide the required infrastructure (the pillar for absolute magnetic observations, the Sun's visibility

or sufficient distance to remote target for azimuth determinations during declination observations).

G. The Earth's ionosphere Monitoring System

The Earth's ionosphere is known to serve as an indicator of various impacts of both natural and technogeneous origin (manifestations of solar and geomagnetic activity, earthquakes, tsunami, thunderstorms, explosions etc.). In the recent years it appeared that the weather and climate cannot be reliably forecasted without taking into account ionospheric processes and atmosphere-thermosphere relations.

The oldest and one of the basic methods of investigating the structure and dynamics of the ionosphere is the method of vertical sounding (VS) using a pulse radiolocator, an ionosonde, located on the Earth's surface. The method is based on a resonance reflection: a radiowave with frequency f , coming down on the ionosphere vertically, is reflected from

the level at which we have $f = f_N = \sqrt{\frac{e^2 N_e}{\pi m_e}}$ (here f_N is

plasma frequency; e is the electron charge; m_e is the electron mass; N_e is the concentration of the electrons). Several other methods of investigating the ionosphere from the Earth's surface include oblique sounding, backscatter sounding, GPS-radiosounding etc. [13].

The method of GPS-radiosounding allows to get the data about variations of the total electron content (TEC) in the ionosphere with high spatial and temporal resolution. Recently, basing on this method, a significant progress in learning the moving ionospheric inhomogeneities has been achieved. The GPS technology allows to detect wave perturbations in the ionosphere basing on phase measurements of the total electron content (TEC) in each of spatially distributed two-frequency GPS receivers. Methods and technologies of GPS detector of ionospheric perturbations allow to investigate ionospheric inhomogeneities with an amplitude up to 10^{-3} from the background value of TEC. The method to define characteristics of the moving ionospheric inhomogeneities (MII) using GPS lattices is described in detail in [13].

H. Lightning Monitoring System

The lightning localization task is very interested for the meteorologist organizations, Airlines, networks operators, military and etc. The Electromagnetic properties of lightning can be measured using the appropriate type of antennas and equipment (Fig. 2).



Figure 2. Some types of antennas used in IKIR [8] for whistler detection and lightning localization

Each lightning stroke location requires the time of arrival from a set of lightning location stations. The placement of the lightning location stations is the very important task. WWLLN [14] is the *World Wide Lightning Location Network* used to monitor lightning occurrences all over the globe (Fig. 3). Lightning stroke positions in Fig. 3 are shown as coloured dots which "cool down" from blue for the most recent (occurring within the last 10 min) through green and yellow to red for the oldest (30-40 minutes earlier). Red asterisks in white circles are active WWLL lightning sensor locations. The terminator (day-night boundary) is shown, with the daylight section of the globe in grey.

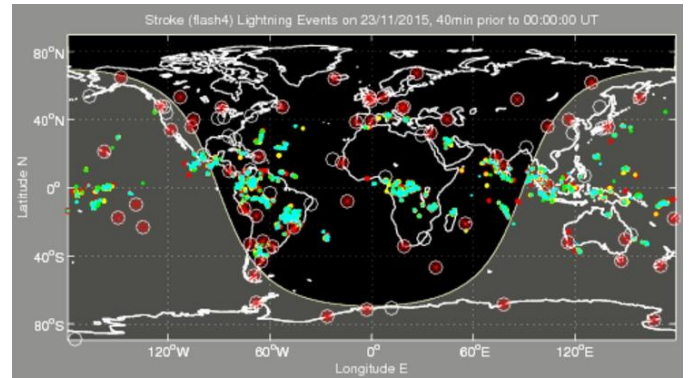


Figure 3. Lightning activity for Earth on 23.11.2015 [14]

Some urgent problems of lightning monitoring and whistlers analysis include:

1. Development of a cluster software-hardware complex for analysis of heterogeneous monitoring data. At the moment the cluster architecture displayed at Fig. 4 has been selected. A cluster is constructed using inexpensive hardware. Examples of the utilized components are: *Intel Core i7* processor, > 32 Gb RAM, hard drives with total volume of more than 1 Tb, a gigabit network controller, as an option — a graphic controller with OpenCL support.

A software cluster is constructed of nodes. A node is a virtual KVM-machine working on the basis of Linux operating system. Software components of the cluster are distributed among the nodes. Examples of the software components are: middleware (*Cloudera* or *MapR*); distributed filesystem *HDFS*; non-relational distributed database (*HBase*, *Cassandra* etc.); frameworks for running distributed programs (*Hadoop*, *Spark* etc.); software for constructing systems of complex events processing (*WSO2*, *siddhi*, *Spark Streaming*, *Apache Storm*, *Drools Fusion* etc.); *OpenCL* framework for parallel computations on graphic controllers; applications server *Glassfish*; *HTTP* server *nginx*; etc.

Depending on the used components, the cluster can perform the following functions: perform distributed computations; analyze heterogeneous data; provide continuous data access; perform complex events processing; safely store data on the cluster; etc.

2. Development of a special-purpose system belonging to the class of complex event processing for online analysis of lightning data. Available software components of this class include: *Siddhi CEP* [15], *WSO2 CEP* [16], *Apache Storm* [17], *Apache Spark Streaming* [18], *Stratio* [19], *Drools Fusion* [20] and etc.

3. Development of Internet-based services to process, analyse and visualize lightning data.

4. Synthesis (design) of stations placement to determine the thunderstorms coordinates and to detect whistlers.

5. Research of radio-physical characteristics of lightning discharges for designing stations of detecting and determining lightning coordinates.

6. Search of the regions that influence the emergence of whistlers in a specified region.

7. Determination of whistlers characteristics (for example, time, frequency characteristics, dispersion etc.).
8. Special-purpose natural-language question-answering system.

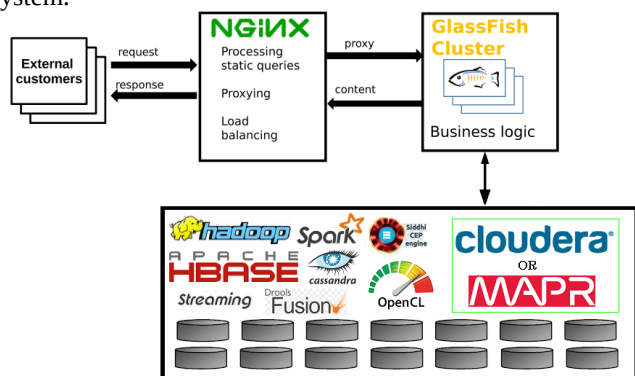


Figure 4. The architecture of cluster software complex for analysis of heterogeneous monitoring data

I. Earthquake Monitoring System

Most often, earthquakes are caused by the movement of tectonic plates. The movement of the these plates can be monitored by various methods. The *Global Seismographic* network monitors the activity of the tectonic plates using a large number of seismological and geophysical sensors. The Seismographic displays depict the ground motion recorded by seismograph stations in real-time [21]. During the time of an earthquake, pressure changes occur in the crust. Hence, pressure sensors can be used to monitor earthquakes. These sensors have the ability to transmit the data wirelessly. Therefore, the data can be monitored wirelessly [22]. Also, GPS can be used to monitor the movement of tectonic plates. This is possible because GPS systems are able to monitor the slightest change in position. Another type of sensor that can be used to monitor the movement of the plates is the acoustic sensor. During an earthquake, stress waves of certain frequencies are produced depending on the crack size. These can be monitored with the help of acoustic sensors [23].

III. FUNCTIONAL SCHEME OF THE ENVIRONMENT MONITORING SYSTEMS ARCHITECTURE DESIGN

Continuous monitoring of the environment is a tedious task. It requires resources and continuous evaluation to analyse the data correctly. To analyse the information many data monitoring nodes are required. As a result, the amount of nodes used increases and hence, the cost of the entire system. Also, the accessibility to the these nodes is not easy, as many of them are placed in remote locations. As a consequence, any malfunction occurring in that specific node cannot be repaired quickly. Thus, the information recorded by this node will not be available till the technician has fixed the issue. The time duration after which the node has to sense its surrounding should be calculated correctly as minor changes will make the data collected will not be valid. Therefore, depending on the parameter to be measured, the time should be considered. For example, the node measuring the pollution in a local water body should measure the pollutant level everyday rather than once a week as the pollutants in the

system change every day. These data monitoring nodes require continuous power supply to operate efficiently. Therefore, additional circuitry should be included to manage the power issues of the device without increasing the cost.

Power consumption of different types of EMS systems varies according to their structure. Considering the structure, systems such as the lightning monitoring systems may require a continuous power supply from the mains supply line. Some sensor systems like the soil sensors work on a continuous battery supply.

One of the interesting problems (especially for the flying sensor networks [24]) is the automatic wireless chargers placement in the WSN structure (Fig. 5). In this problem we know the description of the WSN allocation object, spatial restrictions for allocating wireless chargers. Also, we know the allocation of F-nodes, T-nodes and information collection centres. It is necessary to allocate wireless chargers in such way, that the amount of energy of all nodes after charging become more certain threshold. We have three types of wireless chargers: omnidirectional, directional and managed.

Like in the work [25] we use a model of the WSN structure, where on the functional level the following types of WSN nodes can be defined: (1) functional nodes (F-nodes) that collect information in some neighborhood of their location; (2) transit nodes (T-nodes) that manage routing and retransmit the information collected by F-nodes to the base stations/information collection centers (ICC) to be utilized further; (3) ICCs that manage the WSN and process information collected by the WSN.

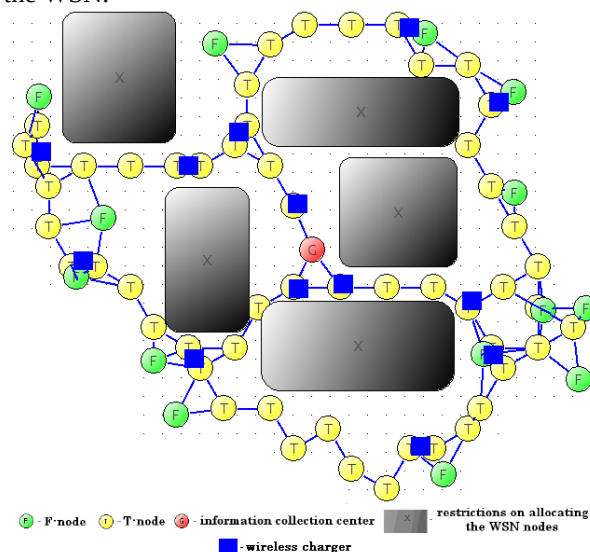


Figure 5. The problem of the automatic wireless chargers placement in the WSN structure

On the basis of works [24,25,26] in Fig. 6 we propose simplified functional scheme of the environment monitoring systems architecture design. In Fig. 7 we show an example of the four main construction steps of the flying sensor network.

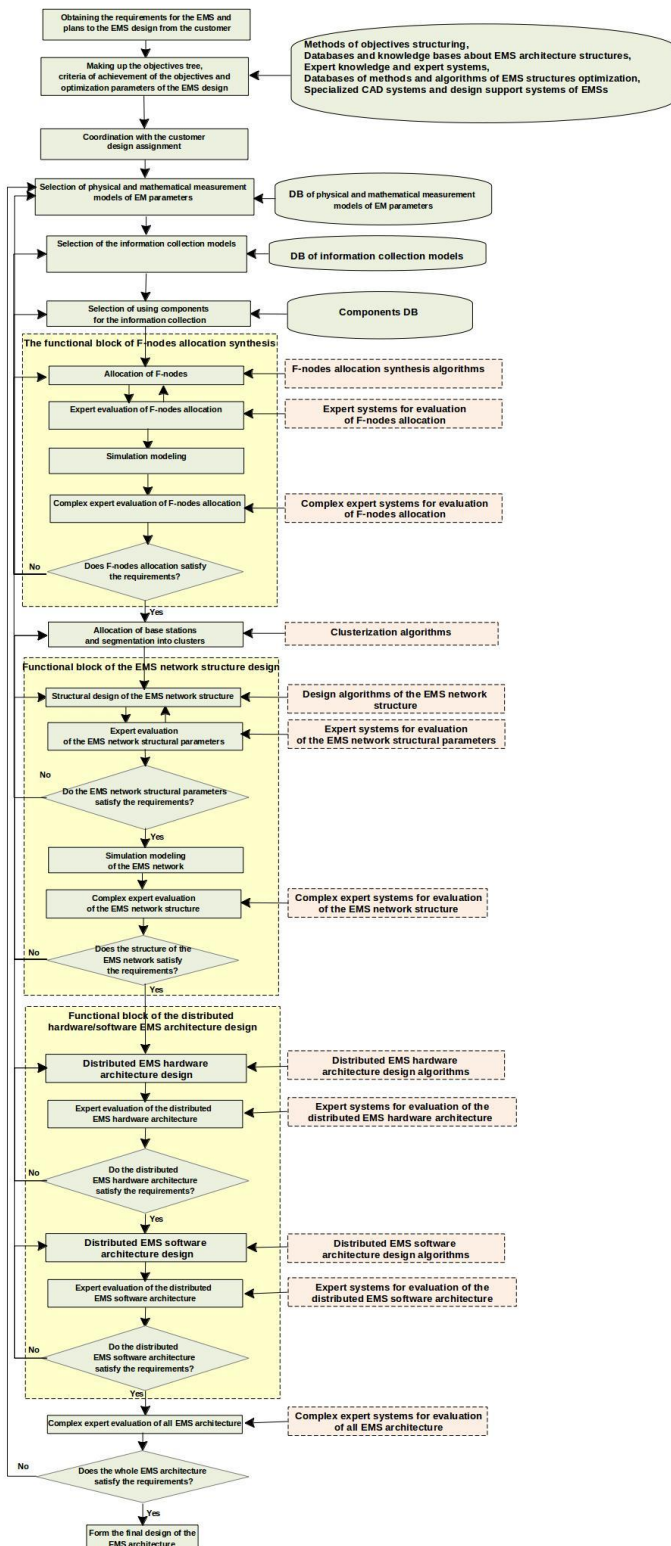


Figure 6. Functional scheme of the environment monitoring systems architecture design

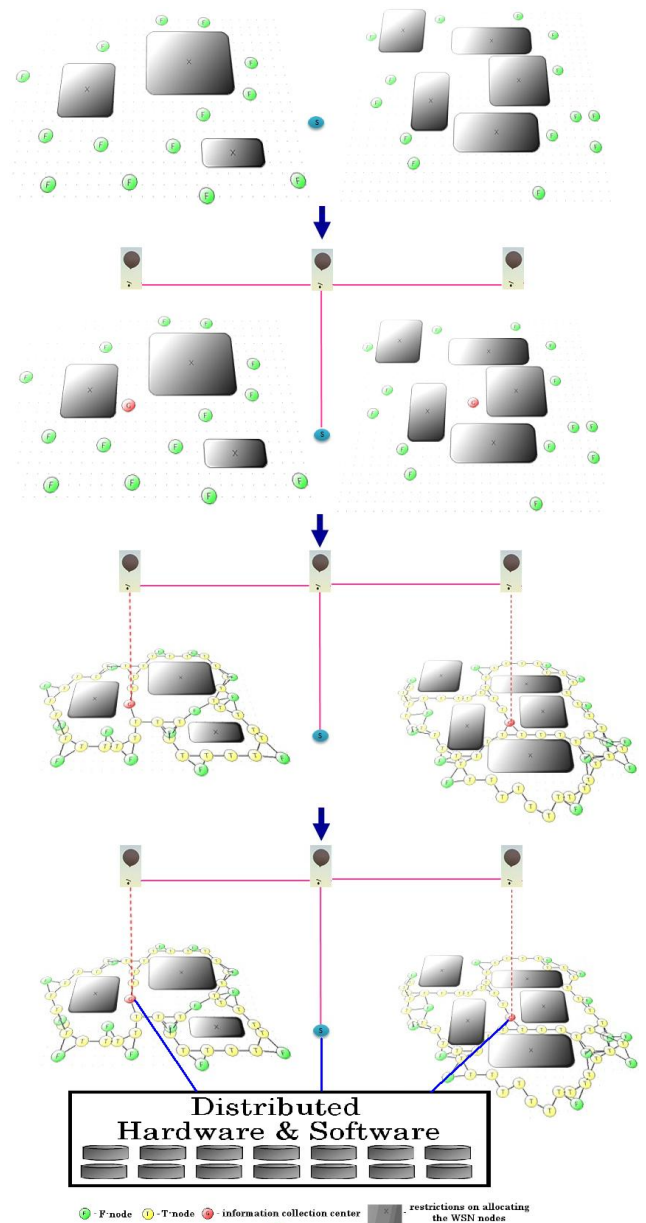


Figure 7. Example of the four main EMS construction steps

IV. CONCLUSIONS

Construction of the EMSs requires solving various complicated problems that relate to different research areas. In this work we propose the simplified functional scheme of the EMS architecture design, which can be the basis for a specialized design support system. Currently in some steps of the EMS architecture design we are using multi-agent bio-inspired algorithms [19] for solving various optimization problems that either do not have exact solution, or the solutions search space is very large and complex constraints of the objective function are present, as well as the problem can be NP-complete.

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