National Centre for Radio Astrophysics

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A comparative study on Lightning Detection Alarm systems : LLN and ATStorm@v3

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Objective: To study and compare available Lightning detection, warning and alarming systems for the GMRT, and find the suitability of Lightning Detection, warning & Alarm systems as per the GMRT observatory requirements.

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A comparative study on Lightning Detection Alarm systems : LLN and ATStorm@v3

Authors : Jitendra Kodilkar, Anil Raut. $ Version 1.0 Mar 24, 2023 $

Objective : To study and compare available Lightning warning systems for the GMRT, and find the suitability of Lightning Detection & Alarm systems as per the GMRT observatory requirements.

- **GMRT Observatory Requirement(s) for the Lightning Detection and Alarm System :**

(1) The Lightning Detection & Alarm system is expected to forecast the lightning warning information at least 15 to 20 minutes before so that lightning hazards due to the 150 Mhz at the sky can be avoided.
(2) Lightning and Thunder storm prediction before week to two weeks ahead is desirable so that the GTAC observation may get scheduled to different observing frequency.
(3) Online Lightning Alarm system data shall be accessible in the observatory.
(4) Lightning Alarm shall be in audio and visual format to control-room, and via SMS/email message to other stake-holders of the GMRT.
(5) Lightning detection systems shall be able to estimate geographical position, and time predictability of the IC (intra cloud lightning), CG (Cloud to Ground).
(6) Lightning Sensor or detector system at the GMRT shall detect lightning for at least 30 km of geographical area with accuracy of 1 to 2 km.
(7) Lightning sensor / detector system shall have 95 % detection reliability. And shall not produce false data due to environmental electronic/electrical systems, car engines, diesel engines etc.
(8) Lightning systems shall be in compliance with the EMI/EMC, and RFI compatibility of the observatory standard.

1. Lightning Process :

Lightning can be divided into two types : **(i)** Flashes with at least one channel connecting the cloud to the ground, known as cloud to ground discharge (CG) ; **(ii)** Flashes with no channel to ground, known as in-cloud (IC), Cloud to cloud (CC) or Cloud to Air (CA).
Most CG discharges are initiated within the cloud charge structure and transfer negative charges to ground in an overall downward developing direction, namely the downward negative lightning discharge. The Lightning process is more or less the same for both types, which is briefed below in step by step process [1] (S*ection -1 and 2* , Notes are taken from Springer publication lecture notes; and [2]) :

Step-0 Preliminary Breakdown (PB) process :

The Preliminary breakdown produces an impulsive narrow radiation burst on a microsecond scale within a cloud (discharge due to separation of charges). The PB process sets the stage for the initiation of a downward-moving stepped leader (SL).

Step-1 Stepped Leader :

This leader is an ionized discharge channel and intermittently develops ***downward to ground*** with an average speed of ~ *200* km/second over a time interval of few tens of microseconds. Each consecutive discrete step is associated with a current pulse of 1 KA with a typical duration of 1 microsecond, and each develops tens of meters in length. During the stepped leader process (SL), emit a dominant electromagnetic energy in the Very High Frequency (VHF 30 to 300 Mhz) band. *A variation in electromagnetic radiation usually occurs from an impulsive radiation burst accompanied by the leader approaching ground with a complex branch structure.*

The monitoring of radiation in the VHF range (30~300 MHz) will allow a lightning detection system with a resolution of 1~10 m but will require more sensors closely deployed because of geometrical attenuation and the absence of over-the-horizon propagation. Space-based satellite lightning detection sensors (CCD focal plane, wide field of view lens) monitor total lightning (**ICs and CGs**) by capturing the optical transient from lightning. No publicly available data is available using the satellite.

Step-3 Return Stroke (Break-through phase or final jump) :

When a stepped leader is progressing downward to ground, one or more **upward-moving leaders** with some tens of meters of length originate from the ground or from the tips of objects and attempt to contact the associated branches of the downward leader. The return stroke discharge channel in the air transforms from a relatively low-conductivity streamer into a high-conductivity plasma channel.

The "**return stroke**" produces more than 99% of a lightning bolt's luminosity and is what we see as lightning. The stroke actually travels FROM the ground INTO the cloud. The return stroke is the most recognizable process of a ground flash in terms of both the optical brightness and the electromagnetic signature.

The return stroke serves to neutralize the leader charge with typical average speed of 1/2 to 1/3 of the light speed. The peak temperature of the lightning channels rises rapidly to 30,000 K creating a high pressure of the order of 10 atmospheres.

The mean initial electric field ranges typically from **6-8 V/m** for the first return stroke and **3-6 V/m** for subsequent return strokes with a range-normalizing to 100 Km. i.e. *These return strokes emit the most powerful electromagnetic radiation in Low frequency (LF – 30 to 300 Khz), and Very Low frequency (VLF – 3 to 30 KHz).* The electric and magnetic field radiated by return strokes shows a conspicuous initial field peak in the recorded waveforms beyond Lambda ~ 10 km (for Lambda ~ 14 km, Frequency is ~ 20 KHz in the upper Very Low frequency : VLF range 3 to 30 KHz).

Step 4 Dart leaders and their return strokes :

After the return stroke ceases flowing up the channel, there is a pause of about 20 to 50 milliseconds. After that, if enough charge is still available within the cloud, another leader can propagate down to the ground. This leader is called a ***"dart leader"*** because it uses the channel already established by the stepped leader (SL), and therefore has a continuous path.
Dart leaders give lightning its flickering appearance and normally are not branched like the initial stepped leader. Not every lightning flash will produce a dart leader because a sufficient charge to initiate one must be available within about 100 milliseconds of the initial stepped leader [2].

The dart leader carries additional electric potential to the ground and induces a new streamer from the ground. The dart leader's peak current is usually less than the initial stepped leader and its return stroke has a shorter duration than the initial return stroke. As additional dart leaders are produced, their peak currents and return stroke durations continue to decrease. If a dart leader takes a different path to the ground, the lightning will appear to dance from one spot to another. This is known as "forked lightning".

The combination of each leader (stepped and dart) and their subsequent return strokes is known collectively as a "stroke". All strokes that use the same channel constitute a single "flash". A flash can be made up of a single stroke, or tens of strokes. ***The actual time between the appearance of the stepped leader in the cloud until the return stroke is about 1/133 of a second.*** *In real time, all one would be able to see is the return stroke (bright flash) and never see the dart leaders progression toward the ground.*

2. Principles of Lightning Detection :

Three kinds of multi-station locating techniques are commonly used for detecting the electromagnetic emissions from lightning : **(I)** Magnetic Direction Finding (MDF) **(II)** Time of arrival (TOA), and **(III)** Interferometry.

(I) Magnetic Direction Finding (MDF) :

The magnetic direction finding (MDF) approach utilizes two horizontal orthogonal loops with directions oriented East–West (EW) and North–South (NS) to detect the magnetic field emitted from a CG flash.

Based on Faraday's law of induction, the acquired voltage of a given loop is proportional to the rate of change of the magnetic flux through a region of space enclosed by the loop. Hence, the tangent of the angle between north and the CG flash location as viewed from the sensor is linearly related to the induced voltage ratio of the NS/EW loops. Magnetic direction finders are susceptible to the unwanted magnetic field from the surroundings. Therefore, it is recommended to select a flat and uniform area, as well as one without conducting structures or buried objects, so as to reduce the site errors.

Two types of crossed-loop magnetic direction finders are commonly used in lightning detection,the narrow band (tuned) and the gated wideband magnetic direction finders.

- **Narrow band :** The general frequency employed in narrow band magnetic direction finders ranges from ***5–10 kHz*** to capture the peak frequency spectrum for lightning. *It has inherent azimuthal errors of the order of 10 degree in close (< ~200 km) lightning detection due to an undesired voltage induced from the non-vertical lightning channel segments, and also due to the inhomogeneous conductivity of the ground beneath the station.*
- **The gated wideband magnetic direction finder :** By adding a gate on the sampling of the magnetic field, initial peak analysis from the return stroke is measured. The gated wideband magnetic direction finder usually operates in the frequency range of a ***few kHz to 500 kHz*** and excludes the ionospheric reflections.

(II) The time of Arrival (TOA) :

The time of arrival (TOA) technique locates lightning on the basis of the arrival times of electromagnetic signals at the detection sensors.

These sensors usually operate in different frequency ranges, detection techniques are categorized as follows :

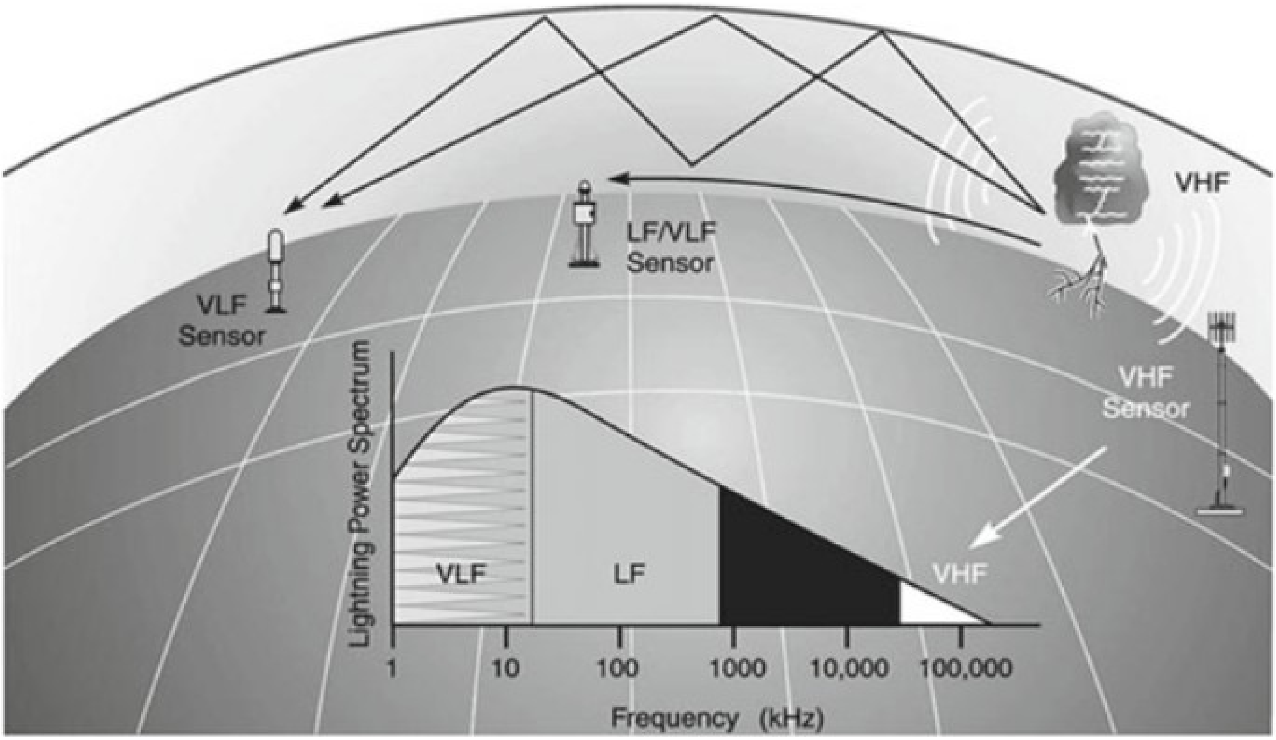
(i) Very short baselines (tens to hundreds meter) - VHF (30 to 300 MHz) :

A very short baseline TOA system consists of two or more TOA receivers and locates lightning from the intersection of hyperboloids deduced from the arrival time differences of every individual VHF pulse. It is capable of resolving air breakdown processes with a time accuracy of tens of nanoseconds.

(ii) Short baseline (tens of kilometers) - VHF (30 to 300 MHz) : A short baseline TOA system typically uses 5-15 stations as a network to map lightning channels in three-dimensions. This system can depict the temporal and spatial development of lightning changes.

(iii) Long baseline (hundreds to thousand kilometers) - LF (30 to 300 KHz) and VLF (3 to 30 KHz) : A long baseline TOA system operates at LF/VLF and generally need four or more stations to assure a unique lightning location as the hyperbolae from two arrival time differences intersect at two points on the Earth's surface remote lightning. The detection system is most sensitive to the "return stroke" and has a wide coverage of lightning detection hundreds to thousand kilometers.

Figure - 1 : Illustration of lightning locating techniques and operating frequencies. The spectral



maximum lies in the upper VLF frequency range, in agreement with radiation expected from a half-wavelength resonant dipole **[1]**

III. The interferometry Technique :

A lightning interferometer is usually composed of two or more identical antennas separated by a few meters and connected by the same narrow-band filter and receiver. The phase difference between two quasi-sinusoidal signals out of the two receivers is then converted into a voltage by a phase detector. Three or more antennas are necessary to form two or more orthogonal baselines in order to obtain the azimuth and elevation of a radiation source. Interferometric systems usually operate in very narrow frequency bands within the VHF band (30~300 MHz)/UHF (ultra-high frequency, 300 MHz–3 GHz) and consist of two or more synchronized interferometers separated by some tens of kilometers or more to locate lightning in three dimensions. These systems have high sensitivity to the signal but also with relatively low signal-to-noise ratio due to the high working frequency and antenna spacing limitation.

3. Modern Lightning Detection System functioning :

The individual lightning detection sensors/antenna units form the lightning location network by sending individual sensor data to the central server (or redundant servers in case of network accessibility problems). The information is then processed using the interferometry techniques and algorithms are applied with greater accuracy to measure the temporal and spatial occurrence of lightning, along with the prediction of lightning based on previously stored location data, and detection algorithm techniques. The data from sensors to the central processors are either sent by the ethernet connection or via 2G/3G/4G virtual private network.

The Central server then pushes the notification, audio/visual and SMS data to the user using web-portal hosted by the vendor, and also through APP running on the mobile.

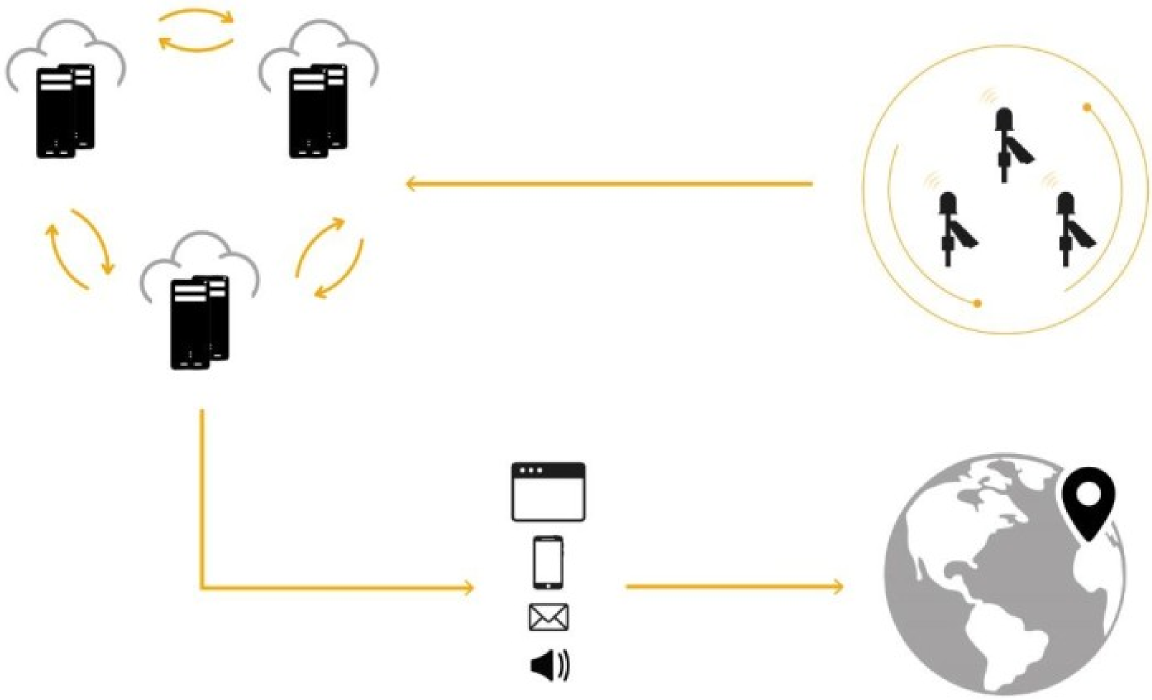


Figure - 2 : Lightning Location network using the multiple Lightning detection sensors/antennae. The data from the individual sensor is pushed to the central server from where lightning location notifications are sent to the user for lightning occurrences and predictions.

4. A comparison of Lightning Detection and Alarm systems : LLN by IITM and ATSTORMv3 by APLICACIONES TECNOLÓGICAS Lightning & Earthing :

We studied the information provided by the vendor using the proposal **[3]** and information available over the web-sites **[4]**. The scope of these internal technical notes is to study the Lightning Location Network (LLN) by the Indian Institute of Tropical meteorology department, Pune, and ATSTORMv3 system by the APLICACIONES TECNOLOGICAS.

The table-1 gives a comparative study of the systems provided by the vendors :

Table - 1 : A Comparative study of the Lightning Detection system :

#	Headings	IITM	ATSTORMv3
1	**Vendor**	The **Lightning detection network or Lightning Location Network (LLN)** (Make : Earth Networks, USA) is joint collaboration work by Indian Institute of Tropical Meteorology (IITM) and other Institutes such as the NCESS (The National Centre for Earth Science Studies).	*Aplicaciones Tecnológicas* has patented technology 'Field-Controlled Electrometric Sensor (FCES, 2005)'. to measure environmental electrostatic fields. The system is named as a ***'ATSTORMv3' storm detection and alerts system.*** The equipment follows IEC (International Electrotechnical commission) 62793 , 62793 2016-standards of Thunderstorm warning systems – protection against lightning.
2	**Lightning Detection Principle**	The sensor detect the flash rate per second, position (Latitude & Longitude) and type of lightning (Intra-cloud , cloud to ground i.e. IC or CG) over the region. **The detection is based on the time of arrival technique (TAO) of detecting Radio frequency signal (1 to 12 MHz Very Low and Low frequency)** [*30 to 300 MHz – Very High Frequency (uncertainty range ~10m), 30 to 300 KHz - Low frequency, 3 to 30 KHz – Very Low frequency. (Low Frequency detection range can be up to 60 km; uncertainty 1 km to 10 km)*].	**(i)** Electrostatic sensor measures the environment electrostatic field **(+/-32 kv/m)** with a resolution of 1 V/m, and can predict localized alert prior to first strike within a range of 20 km. **(ii)** Electromagnetic field sensor technique receives IC or CG radio frequency signals from clouds approaching to the location within a range of 40 to 60 km. This works on time of arrival technique (TAO) at 1 Hz (Very low frequency). This sensor notices/records lightning information after occurrence.
3	**Lightning detection Sensor**	**Lightning sensor :** Earth Networks Lightning Sensor (USA) **Method :** Time of Arrival technique of Radio wave from 1 Hz to 12 MHz **Types of Lightning Detected :** Cloud-to-Ground (CG) and In-Cloud (IC) strokes. **Location Accuracy :** <100 meters (density dependent). **Detection Efficiency :** > 95%; IC: > 85% (density dependent). Sensor Timing Accuracy : <15 nanoseconds.	**(i) Electrostatic sensor :** **Detection range:** -32kV/m to 32kV/m Resolution (max) : 1V/m **Range : 20 km** **(ii) Electromagnetic Sensor :** Method : Time of Arrival technique of Radio wave ~ 1 Hz? **Range :** 40 km **Communication :** 2G/3G Mobile VPN* Ethernet/Satellite on non-availability of Mobile communications. **Detection Efficiency :** > 90 %

#	Headings	IITM	ATSTORMv3
		Communication : BSNL FTTH	**Working temp:** -40ºC to +85ºC
4	**System Functioning**	Lightning Detector consists of Antenna, GPS, DSP, data cable, and Earth networks Network Appliances (Ethernet connection). There are 83 such antennas in India (Maharashtra-13) called **LLN** (*Lightning Location network*). A real-time/recorded data sent to the central processor at IITM using Ethernet connection. Using this data, ***an interactive web map*** is hosted by IITM (https://www.tropmet.res.in/~lln/current-lightning.html) which can give Lightning Alerts. Refer to the **Figure-1** LLN Antenna.	No user interaction is required, the system continuously monitors local conditions and sends data to the central servers from which the alarms are processed and sent to users in real-time via multiple channels. (i) Autonomous communication via Virtual Private Network (VPN) - safe, reliable protocol (ii) Redundancy through 2G/3G/4G and LAN communication (iii) Global M2M and dedicated channels with secured, accurate data delivery (iv) Satellite communication for remote sites with no GSM coverage
5	**Installation Requirements**	**A single Earth Network Lightning sensor (Antenna)** can be mounted on a terrace of CEB/Multipurpose building. It requires UPS power supply and Ethernet Fiber connection. **UPS unit :** Hykon 1KVA unit with two 75 AH Exide batteries. **Internet :** BSNL FTTH connection and accessories.	**In the proposed system, three detection units are proposed, one in CEB, second near C08, and third out-side CSQ near S01/S02 location.** Except Power supply no other infrastructure required. **Power supply:** 110V ~ 250VAC Power Consumption : 15 Watts. **Communication :** The Central processor of the company is via 2G/3G Communication using private VPN. **Power Backup (7 days)** is guaranteed through solar panel power, and AC battery back up by the company.
6	**Dependencies**	**(i)** Continuous Internet connection to the Central Processing server is a must. **(ii)** Antenna maintenance or problem handling	**(i)** Net dependencies are optional. Use of Mobile 2G/3G data may invite RFI. **(ii)** Antenna maintenance, Web-portal may incur budget for annual maintenance contract.

#	Headings	IITM	ATSTORMv3
		requires the IITM team (although rarely).	**(iii)** For audio , integration with the Control & Monitoring system with Ethernet connection required a separate module. i.e. **Remote Relay module -** The remote relay module is offered as an additional accessory to control autonomous alarm systems located at any distance from the reading Detection Unit as well as integration of the ATSTORM@v3 system into any internal control or monitoring systems.
7	**Alarming Facility**	**(i) Web Portal -** https://www.tropmet.res.in/~lln/current-lightning.html **(ii)** Can configure audio Alarm with dedicated link and separate configuration system to access IITM central server data for which separate requirement, and its feasibility need to be checked. **(iii)** Damini APP is available over Windows, Web-browser and mobile App.	**(i)** APP - Proprietary APP for real time PUSH notifications and alerts. **(ii)** Private user portal to manage and monitor the different detection unit networks. Read real time data, Different alert levels, and feasibility of acquiring past data. **(iii)** For local audio /visual alarm available through Remote Relay module.
8	**Reliability**	95 %, 20 km to 60 km with ~10 meter accuracy of lightning.	90 to 95 % - Prior Alarm notification before lightning occurs.
9	**Main Pros & Cons**	**Pros : (i)** Vendor is available in the vicinity of the khodad (IITM, Pune) **(ii)** Consultation with other lightning hazard preventive solutions can be developed with collaborative work. **(iii)** May be free of cost antenna installation at the CEB. **Cons : (i)** Dependencies of IITM web-portal for monitoring the Lightning Alarm. **(ii)** Maintenance on the site may get delayed due to remote-site and procedure.	**Pros : (i)** Monitored through IoT Remotely monitored via AT Control Room ensuring correct and continued operation. **(ii)** Maintenance free, and no s/w updates required. **(iii) For independent Lightning Detection and Alarm (without central port, feasibility needs to check off accessing three detection sensors using locally installed dedicated s/w).** **Cons : (i)** Maintenance of problem attending to the

#	Headings	IITM	ATSTORMv3
			remote site may invite delay once in a while. **(ii)** Can not use 2G/3G based VPN due to the RFI. Hence a dedicated module must be purchased (Remote relay module?)

5. Conclusion and Executive Summary :

(i) Lightning Detection and Alarming system is topmost priority of the GMRT observatory as the past Lightning incidents reported to damaged several antenna electronics systems such as the Front-end electronics, interlock protection systems.
(ii) Lightning Detection and alarming system desirable to give notification in audio and visual format prior to lighting occurrence at least 10 to 15 minutes earlier so that the Lightning hazards due to the 150 MHz feed misalignment can be avoided.
(iii) During the thunderstorm and Lightning time, it is possible that the network, and electrical system may not work outside the GMRT premices, hence it is desirable to install a private vendor system (ATSTROM@v3) if it provides individual sensor network connection, along with the central detection-server application installed at the GMRT premices using the Ethernet connection. This can then avoid the network and electrical failure problem, and can report directly.
(iv) In case a private vendor doesn't provide this, then LLN system IITM is desirable because it may give similar facilities at free of cost, and the vendor is available near the site (i.e. any problem attending or maintenance is possible without any delay as compared to the private vendor).

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