LoRa Mesh Networking with Meshtastic for Amateur Radio Emergency Communications in India: Regulatory Considerations, Link-Budget Analysis and Open Questions

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***Abstract*—Amateur radio has a long history of adopting infrastructure-independent digital modes. This article examines Meshtastic, an open-source LoRa-based mesh firmware, as a candidate technology for short-message and position reporting in the Indian context. The LoRa physical layer and the managed-flood (plus next-hop) routing of current firmware are described. Two distinct operating modes available in India are separated: unlicensed operation in the 865–868 MHz band under G.S.R. 853(E) and licensed operation on the 70 cm amateur allocation. A worked free-space link-budget comparison with 1200-baud APRS is presented under explicitly stated assumptions; the calculated advantage of LoRa is shown to be modest once frequency and typical power differences are taken into account. Related systems (LoRa APRS, AREDN, Winlink, JS8Call) are briefly reviewed. The principal practical advantage of Meshtastic in India is argued to be infrastructure independence rather than raw link budget. No new field measurements are reported. A field-test protocol is proposed, and open regulatory and scaling questions are listed.**

***Index Terms*—Meshtastic, LoRa, mesh networking, APRS, amateur radio, emergency communications, ISM band, India, 865 MHz.**

I. INTRODUCTION

Amateur radio has always attracted operators interested in the growing edge of communication technology. Packet radio in the 1980s and the Automatic Packet Reporting System (APRS) in the 1990s are well-known examples [1]. Experimentation with new modes is consistent with the purpose of the amateur service as defined in the ITU Radio Regulations: self-training, intercommunication and technical investigation [2].

Meshtastic is a recent open-source firmware that turns low-cost microcontroller and LoRa radio boards into nodes of a self-forming, self-healing mesh [3]. Nodes exchange short text messages and position data without cellular coverage, an Internet connection or fixed repeater infrastructure. Every node also acts as a relay, so coverage expands as additional nodes are added.

Opinion within the amateur community remains divided. Some operators regard the technology primarily as a convenience for outdoor recreation; others have begun incorporating city-scale meshes into emergency-communications planning. Peer-reviewed evaluation of Meshtastic remains limited.

This article makes four contributions. First, it describes the LoRa physical layer and the Meshtastic network layer (including next-hop routing introduced in firmware 2.6) at a level suitable for an amateur-radio technical audience. Second, it sets out the Indian regulatory position as two clearly separated operating modes. Third, it presents a worked free-space link-budget comparison with 1200-baud APRS under explicitly stated assumptions. Fourth, it proposes a practical field-test protocol. No new experimental measurements are reported; the numerical estimates in Section 5 are analytic and require field confirmation.

II. THE LORA PHYSICAL LAYER

2.1 Chirp Spread Spectrum

LoRa is a proprietary chirp-spread-spectrum modulation developed by Semtech [4]. Each symbol is

a chirp whose frequency sweeps linearly across the channel bandwidth BW. The spreading factor SF determines the number of chips per symbol (2^SF) and therefore the number of bits carried by each symbol. Correlation at the receiver permits reliable decoding of signals whose power lies below the noise power measured in a conventional narrowband receiver [4], [5]. Increasing SF by one double the symbol duration and improves the demodulation threshold by approximately 2.5 dB, extending range at the expense of data rate.

With coding rate CR = 4/(4+n), the principal relations are:

$$T_s = 2^{SF} / BW$$

$$R_b = SF \times (BW / 2^{SF}) \times CR$$

$$S = -174 + 10 \log_{10}(BW) + NF + SNR_{min}$$

where T_s is symbol time, R_b is bit rate, S is receiver sensitivity in dBm, BW is in hertz, NF is noise figure in dB, and SNR_{min} is the minimum signal-to-noise ratio required for demodulation. Representative thresholds are −7.5 dB (SF7), −17.5 dB (SF11) and −20 dB (SF12) [4]. Table I applies these relations to three common Meshtastic presets, assuming NF = 6 dB.

Table I

Computed data rate and sensitivity for three Meshtastic presets (NF = 6 dB)

Preset	SF	BW (kHz)	CR	Bit rate	SNR_min (dB)	Sensitivity (dBm)
ShortFast	7	250	4/5	10.94 kbps	−7.5	−121.5
LongFast	11	250	4/5	1.07 kbps	−17.5	−131.5
LongSlow	12	125	4/8	183 bps	−20.0	−137.0

Note: Values are calculated, not measured. Real receivers typically differ by a few decibels. Preset parameters follow Meshtastic documentation [6] and should be verified against the firmware version in use.

2.2 The Cost of Range

LoRa obtains its sensitivity advantage at the expense of data rate. The default LongFast preset carries approximately 1.07 kbps, and a single LoRa frame is limited to 255 bytes. Short text, position reports and low-rate telemetry therefore fit the technology well; voice, images and bulk file transfer do not.

III. MESHTASTIC NETWORK LAYER

3.1 Nodes and Firmware

A typical node pairs a low-power microcontroller (commonly ESP32 or nRF52) with a LoRa transceiver such as the Semtech SX1262 or SX1276. The firmware implements routing, duplicate-packet suppression, optional GPS position broadcasting, AES channel encryption was permitted by regulation, and a Bluetooth interface to a companion telephone application [3], [6]. From the operator's perspective the experience resembles a conventional messaging application: the device is paired, a message is typed, and delivery is left to the mesh.

3.2 Managed Flooding for Broadcasts

Broadcast traffic employs managed flooding. A node that receives a packet rebroadcasts it once, subject to two constraints. A hop-limit field is decremented at each relay and forwarding ceases when the field reaches zero. A short-term cache of recently observed packet identifiers prevents a node from retransmitting a packet it has already handled [7]. The default hop limit is three; the header field itself is three bits wide.

Before rebroadcasting, a node inserts a random delay whose window depends on the received signal-to-noise ratio. Distant nodes, which hear the packet weakly, tend to transmit earlier. A node that overhears another relay during its waiting interval cancels its own transmission [7], [8]. Nodes configured with the Router role continue to relay even after hearing another retransmission, a behaviour that suits fixed elevated sites. Role selection is therefore an important deployment decision.

3.3 Next-Hop Routing for Direct Messages

Beginning with firmware 2.6, direct messages follow a different procedure. The first transmission still floods. When a reply returns through a particular relay, that relay is recorded as the next hop for subsequent packets. Thereafter only the designated next-hop node retransmits the packet. If the next hop remains silent after the final retry, the sender falls back to flooding [7]. Earlier characterisations of Meshtastic as purely

flood-based are therefore outdated for directed traffic, although broadcast traffic continues to flood.

3.4 Reach and Hop Arithmetic

A packet whose hop limit is three may traverse at most three relays and therefore up to four radio links. Maximum theoretical reach is consequently approximately four times the single-link distance rather than three times. Actual single-link distance depends on antenna height, terrain, frequency and transmit power; each site requires its own measurement. This article does not assume a typical value.

3.5 Suitability of Flooding for the Traffic Profile

Flood routing is less airtime-efficient than a protocol that computes and follows a single path. For the low, bursty traffic volumes characteristic of text messaging and position reporting the inefficiency is acceptable, and the advantages are significant: absence of routing tables, no convergence delay after topology changes, and robust behaviour when nodes move or fail. The cost grows with node density. Studies of LoRa networks have shown that collisions and channel contention impose a practical scaling limit [9], [10]. The usable node count for a dense Meshtastic mesh on a single channel has not yet been well characterised in the literature.

IV. REGULATORY FRAMEWORK IN INDIA

Two operating modes must be distinguished. Mode 1 is unlicensed low-power operation in the 865–868 MHz band; it requires neither an amateur licence nor a callsign, and encryption is permitted. Mode 2 is licensed amateur operation on the 70 cm band; it requires a valid licence and callsign identification, and encryption is prohibited. Only Mode 2 constitutes amateur radio in the legal sense. Both modes may be useful for club emergency work, but the applicable rules differ and must be stated clearly in any deployment policy.

4.1 Mode 1: Unlicensed 865–868 MHz

The governing instrument is G.S.R. 853(E) of 10 December 2021, which exempts low-power short-range devices operating in 865–868 MHz from individual licensing [11]. Limits are specified by device category and are summarised in Table II.

Table II
Summary of device categories under G.S.R. 853(E), 2021 [11]

Category	Power limit (e.r.p.)	Bandwidth	Duty cycle
Non-specific short-range devices	25 mW	≤ 50 kHz per channel (FHSS, ≥ 58 hop channels)	1 %
Tracking, tracing and data acquisition	500 mW (APC required)	≤ 200 kHz	≤ 10 % (access points); ≤ 2.5 % otherwise
Wideband data transmission	25 mW	> 600 kHz and ≤ 1 MHz	≤ 10 % (access points); ≤ 2.8 % otherwise
RFID applications	2 W (selected channels)	≤ 200 kHz	Interrogator ≤ 4 s per channel

Note: Summary prepared from the rule text. Operators must confirm every figure against the current gazette notification before deployment.

Meshtastic's IN region setting places the radio in 865–867 MHz with a firmware power ceiling of 30 dBm and no enforced duty-cycle limit [6]. The documentation explicitly states that the power value is a firmware ceiling, not a national legal limit. Selecting the IN region therefore sets the correct frequency range but does not enforce Indian power or duty-cycle restrictions; those remain the operator's responsibility. The default US region preset (902–928 MHz) is not appropriate for India.

An open compliance question concerns channel bandwidth. The default LongFast preset occupies 250 kHz, which exceeds the 200 kHz figure listed for the tracking and data-acquisition category. Which category properly applies to a mesh messaging device, and whether LongFast is permissible under that category, should be clarified with the Wireless Planning and Coordination Wing before any organised club deployment. Equipment type approval requirements for imported boards should likewise be verified.

4.2 Mode 2: Licensed Amateur Operation on 70 cm

ITU Region 3 provides for amateur use in 430–440 MHz [2]. In India the authorised allocation for most licence grades is 434–438 MHz on a secondary basis [12], [13]. Whether a LoRa emission falls within the emission classes permitted for each licence grade remains a question to be confirmed with the regulator. Amateur operation carries the customary obligations: the station must identify with its callsign, and the meaning of transmissions must not be deliberately obscured. Meshtastic documentation instructs licensed operators to enable the HAM operating mode, disable encryption and transmit a callsign [6]. The firmware supports these settings; responsibility for correct configuration rests with the operator.

V. LINK-BUDGET COMPARISON WITH APRS

5.1 APRS in Brief

APRS conveys 1200-baud Bell 202 AFSK on a conventional FM transceiver. Fixed digipeaters extend range and Internet-connected igates bridge traffic onto APRS-IS for global visibility [1]. Operating frequencies vary across ITU Region 3. No single authoritative frequency for India was identified during preparation of this article; local practice should be confirmed with the Amateur Radio Society of India or active operators. Where digipeater and igate density is high, APRS performs well. Where that infrastructure is sparse, utility is limited to direct simplex range. No quantitative inventory of Indian digipeaters is used here; such data would allow a future study to measure the infrastructure gap rather than assert it.

5.2 Worked Free-Space Estimate

Maximum allowable path loss (MAPL) is defined as

$$MAPL = P_{tx} + G_{tx} + G_{rx} - S$$

Free-space path loss (dB) with distance d in kilometres and frequency f in megahertz is

$$FSPL = 32.44 + 20 \log_{10}(d) + 20 \log_{10}(f)$$

A frequency change from 144.39 MHz to 866 MHz increases free-space loss by $20 \log_{10}(866/144.39) \approx 15.6$ dB. Table III subtracts this penalty from the UHF cases so that every adjusted figure may be read as an equivalent loss budget at VHF. Both ends are assumed to use 0 dBi antennas. LoRa sensitivity is taken from Table I for the LongFast preset. The AFSK sensitivity of −112 dBm is an assumption for a typical FM receiver achieving a low packet-error rate; real receivers vary.

Table III

Worked link-budget estimate under stated assumptions (0 dBi antennas, no cable loss)

Case	System	Band (MHz)	Tx power (dBm)	Sensitivity (dBm)	MAPL (dB)	MAPL adj. to VHF (dB)
L1	LoRa LongFast	866	20	−131.5	151.5	136.0
L2	LoRa LongFast	866	27	−131.5	158.5	143.0
L3	LoRa LongFast	866	30	−131.5	161.5	146.0
A1	APRS 1200 AFSK	144.39	37	−112.0	149.0	149.0
A2	APRS 1200 AFSK	144.39	30	−112.0	142.0	142.0

L1 = 100 mW node; L2 = 500 mW (tracking-category e.r.p.); L3 = 1 W firmware ceiling; A1 = 5 W APRS radio; A2 = 1 W APRS radio.

At equal transmit power of 30 dBm (cases L3 and A2) the spread-spectrum demodulation advantage is 19.5 dB. After the free-space frequency penalty of 15.6 dB the net advantage is approximately 4 dB. At more typical operating powers, the comparison reverses: a 5 W APRS link (A1) retains a margin of 13 dB over a 100 mW LoRa node (L1) and 6 dB over a 500 mW node (L2).

Three important caveats apply. Real propagation paths include terrain loss, and lower frequencies diffract more effectively around obstacles. Antenna gain, height and feed-line loss differ between a compact LoRa node and a vehicle-mounted APRS installation. The assumed AFSK sensitivity may also shift the result by several decibels. Consequently, the common claim of a substantial LoRa advantage over APRS at equal power holds only narrowly under free-space assumptions, and range under realistic conditions and typical powers may favour APRS. The strongest practical argument for Meshtastic in the Indian setting is therefore not raw link budget but independence from existing digipeater infrastructure (Section 6). Only measurement can settle the quantitative question; a protocol is outlined in Section 9.

VI. RELATED SYSTEMS

Treating APRS as the sole point of comparison omits several systems that overlap with Meshtastic in useful ways. LoRa APRS carries APRS-format packets over LoRa modulation and gates them to APRS-IS, providing a direct bridge between the two ecosystems [14]. AREDN constructs a broadband amateur mesh from commodity Wi-Fi hardware; throughput is far higher than LoRa but links are shorter and infrastructure requirements greater [15]. Winlink has a long record of moving email over HF and VHF in emergency situations [16]. JS8Call supplies weak-signal keyboard messaging on HF [17]. Other open LoRa mesh projects exist and merit separate study.

Meshtastic occupies a comparatively narrow niche: a low-rate layer for short messages and position reports that requires no pre-existing infrastructure. It complements the systems listed above rather than replacing them. Where APRS infrastructure is already dense, Meshtastic is best regarded as a useful addition. Where that infrastructure is thin, Meshtastic allows a group of operators to form a working mesh as soon as the nodes are powered on in reasonable proximity.

VII. EMERGENCY COMMUNICATION IN INDIA

During a major flood, earthquake or cyclone, cellular networks are frequently among the first systems to saturate or fail, and fixed repeaters may lose power or suffer physical damage. HF remains available but demands antenna erection, propagation assessment and a level of operator skill that is not uniformly distributed even within a club. A pre-positioned Meshtastic mesh offers a complementary capability: simple, low-power nodes that provide text messaging and automatic position tracking for a response team, independent of external infrastructure.

India's disaster profile aligns with this use case. Flood-prone states (Kerala, Assam, Bihar, Odisha and others) experience recurring large-scale events, and coastal districts face regular cyclone risk [18]. Indian amateurs have supported relief operations in past disasters. Club-level budgets can accommodate node hardware, whose unit cost is substantially lower than that of a typical handheld transceiver.

Claims concerning battery endurance must be treated with caution. Run time depends on node role, display usage, GPS reporting interval and transmit power; solar-panel sizing depends on site and season. Each club should measure the figures for its own hardware before relying on them operationally.

Three additional issues require advance planning. First, a node that broadcasts position reveals the location of its carrier. Second, channels left on the default encryption key afford little confidentiality [6]. Third, amateur-band operation forbids encryption, so sensitive traffic (for example casualty lists) needs a pre-agreed handling policy. Coordination partners in India include the Amateur Radio Society of India, the National Institute of Amateur Radio and state disaster-management authorities. American ARES/RACES structures are not directly transferable; Indian clubs require their own organisational arrangements.

VIII. HARDWARE AND DEPLOYMENT

Numerous boards run the same firmware and the same companion applications, keeping the barrier to entry low. ESP32-based boards with an SX1262 or SX1276 radio, GPS module and battery management (for example LILYGO T-Beam and Heltec V3) serve as common reference designs. Modular nRF52 platforms such as RAK WisBlock are better suited to permanent or solar-powered sites because of lower sleep current and easier sensor integration. E-paper handhelds such as the LILYGO T-Echo extend battery life for portable use.

A first node can be placed on the air without soldering or conventional programming: firmware is written with a browser-based flasher, and region, callsign and encryption settings are configured from the telephone application. Antenna choice and mounting height influence range more than the particular board selected; a well-sited antenna should therefore take precedence over a more expensive node.

IX. PROPOSED FIELD-TEST PROTOCOL

A field study is required to test the analytic estimates of Section 5 under realistic Indian conditions. Three route classes are suggested: urban streets, open roads and hilly terrain. Fixed nodes would be placed at known heights; mobile nodes would travel predetermined routes and stop at marked intervals. At each stop the study would record RSSI, SNR, packet-delivery ratio over a fixed number of messages, and the greatest distance at which delivery remains above

90 %. A 1200-baud APRS tracker would traverse the same routes so that both systems experience identical terrain and weather. Each configuration should be repeated on several days. Reports must state firmware version, modem preset, antenna type and height, transmit power and region setting, and should present confidence intervals rather than single-run results.

X. LIMITATIONS AND OPEN QUESTIONS

Throughput is low by design. Meshtastic is not a substitute for voice coordination or for HF traffic handling during sustained high-volume emergency operations; it functions best as a position-tracking and short-message layer that complements existing VHF and HF practice.

Flooding scales poorly with increasing node density; the practical ceiling for a single channel in a dense urban deployment has not been adequately characterised. Interoperability with APRS-IS and other tracking systems remains an integration task rather than a solved problem. Security and location-privacy policies need explicit definition before operational use. The compliance questions raised in Section 4 require answers from the regulator. Firmware evolves rapidly, so any measurement campaign must record the exact version employed. Finally, the assertion of sparse Indian APRS infrastructure still awaits quantitative support.

XI. CONCLUSION

Meshtastic is not a replacement for any single existing amateur-radio mode. It offers a low-cost, infrastructure-independent mesh layer for short messages and position data. The free-space link-budget estimate presented here indicates that the physical-layer advantage over 1200-baud APRS is narrower than popular accounts suggest once carrier frequency and typical transmit powers are taken into account. The principal practical argument for Meshtastic in India is therefore independence from digipeater infrastructure rather than superior range at equal power.

Correct use in India requires clear separation of unlicensed and licensed operating modes, verification of power, duty-cycle and bandwidth limits against current regulations, and measurement of actual range on representative terrain. The next necessary step is a documented field campaign; the protocol outlined in Section 9 provides a starting point for that work.

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