Compressed Sensing Based Detection of Localized Heavy Rain Using Microwave Network Attenuation

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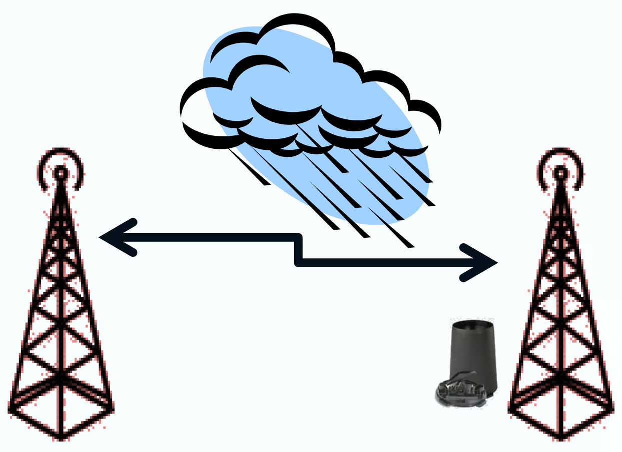
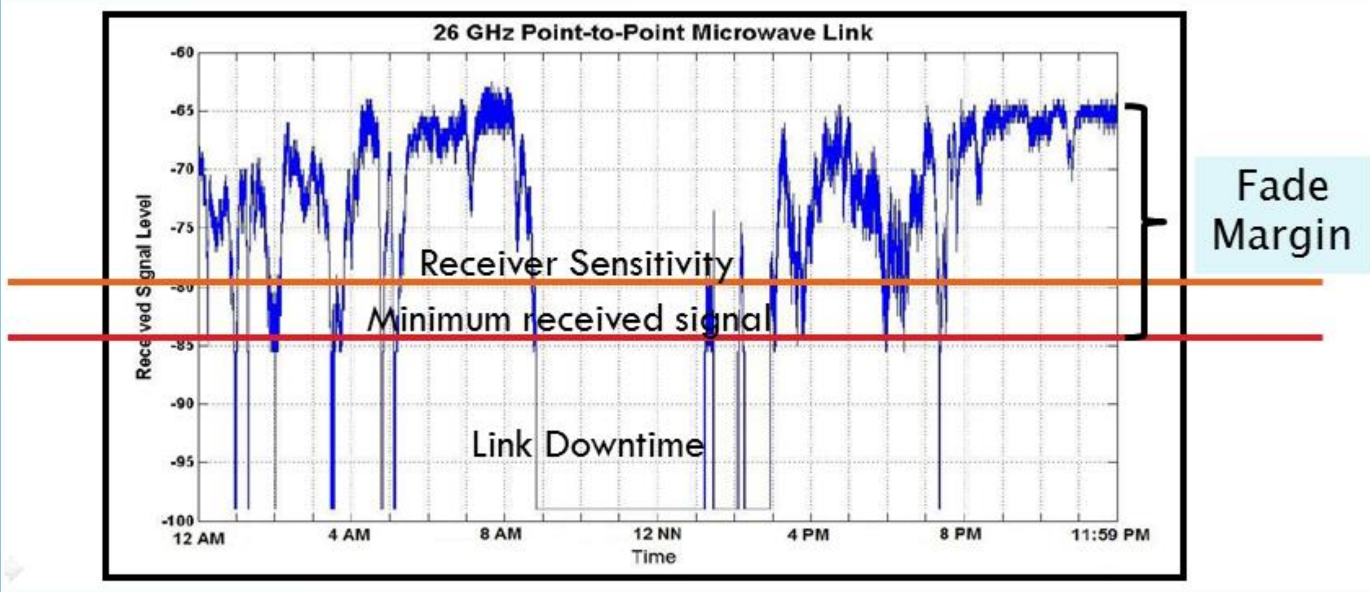
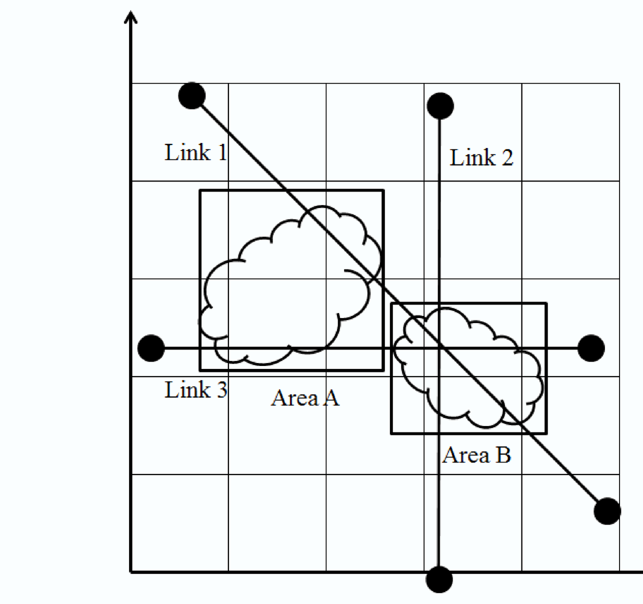
Microwave Mesh Network for Rain Detection



- The effective covered area of the links fit the size of rain clouds (less than 5 km)
- Already deployed as commercial links
- Designed to tolerate rain by a certain fade margin

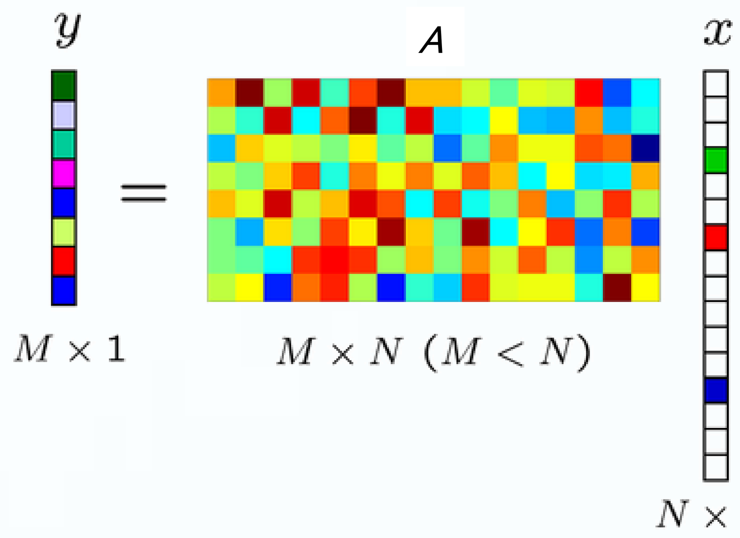




- Microwave mesh network
- Each link's signal strength gets attenuated
- 1-2 links attenuated at the same time can indicate the rain location
- More crossing links – more accurate detection

Objective:
To implement a compressed sensing-based method to detect localized heavy rain from the measured rainfall attenuation

Compressed Sensing Reconstruction

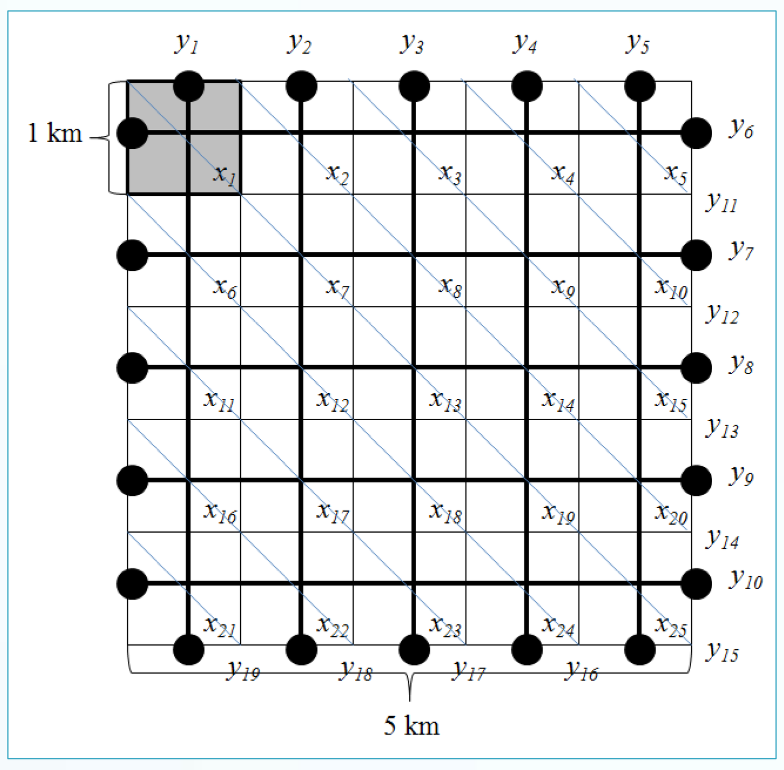


- measurements vector y
- measuring matrix A
- $y = Ax$, where x is sparse vector to be recovered

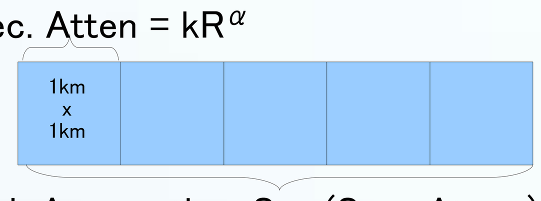
- Solution to underdetermined system through convex optimization (e.g. linear programming)

$$\hat{\mathbf{x}} = \arg\min_{\mathbf{x}} \|\mathbf{x}\|_1 \quad \text{subject to } \mathbf{y} = \mathbf{Ax}$$

Network Model

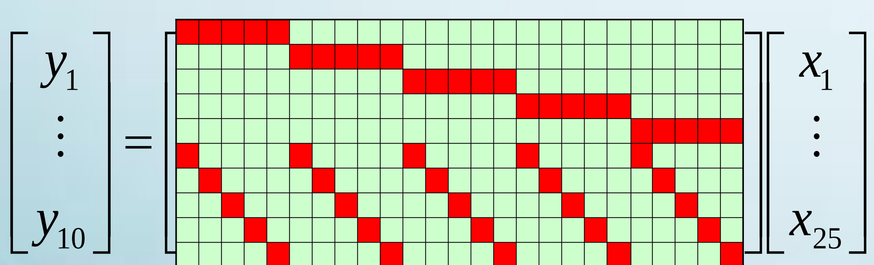


Spec. Atten = kR^{α}



Link Attenuation=Sum(Spec.Atten.)

- 5km x 5km area in Okinawa
- Japan radar rain data (1km x 1km every 5 mins)
- 1 area ($x_1 - x_{25}$): 3 crossing links
- For 25 GHz, vertical polarization: (from ITU-R P.838.3)
  $k_v = 0.1533$
  $\alpha_v = 0.9491$
  R = rain rate

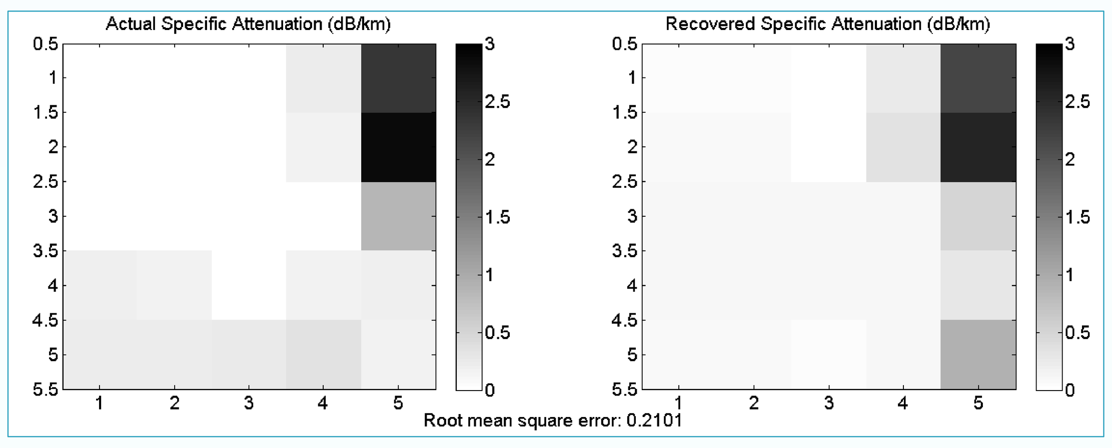


- y : link atten. measurements
- A : measurement matrix defined by areas with microwave links, where red and green are 1 and 0,
- x : unknown or the specific attenuation of a 1km x 1 km area

Results

Location Detection

- False positive rate: 4.03% (Out of 12733 samples, 45 were falsely marked moderate, 1 marked heavy, the rest light to negligible rain
- False negative rate: 5.69×10^{-5}% or 18 data points



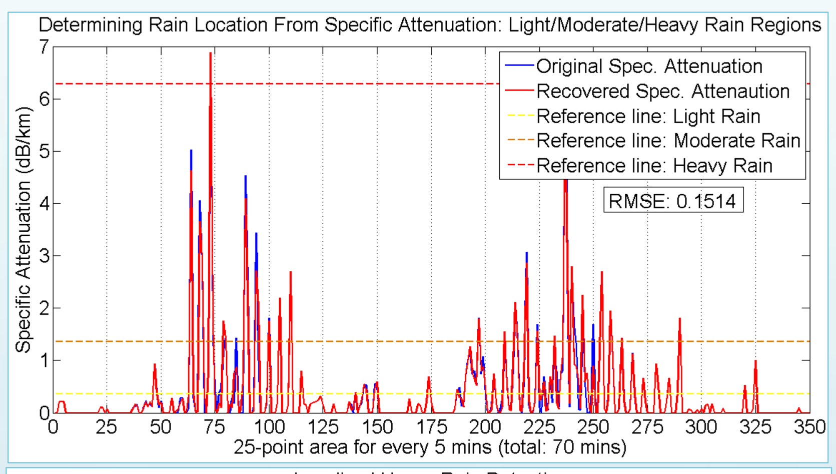
Recovered specific attenuation that causes high false positive rate

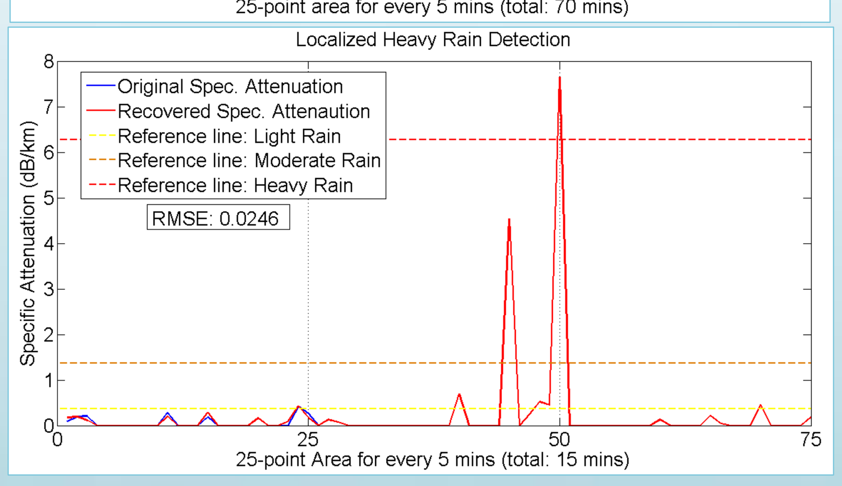
Rain Rate Detection

TABLE I. EVALUATION OF RECOVERED VALUES BASED ON RAIN RATE

Rain Rate (mm/hr)		Specific Attenuation (dB/km)	# of Data Points	RMS Error
No Rain	0	0	148,483	0.02
Light Rain	< 2.5	< 0.37	105,761	0.06
Moderate Rain	2.5 ~ 10	0.37 ~ 1.36	49,801	0.16
Heavy Rain	10 ~ 50	1.36 ~6.28	11,536	0.46
Violent Rain	> 50	> 6.28	544	1.27

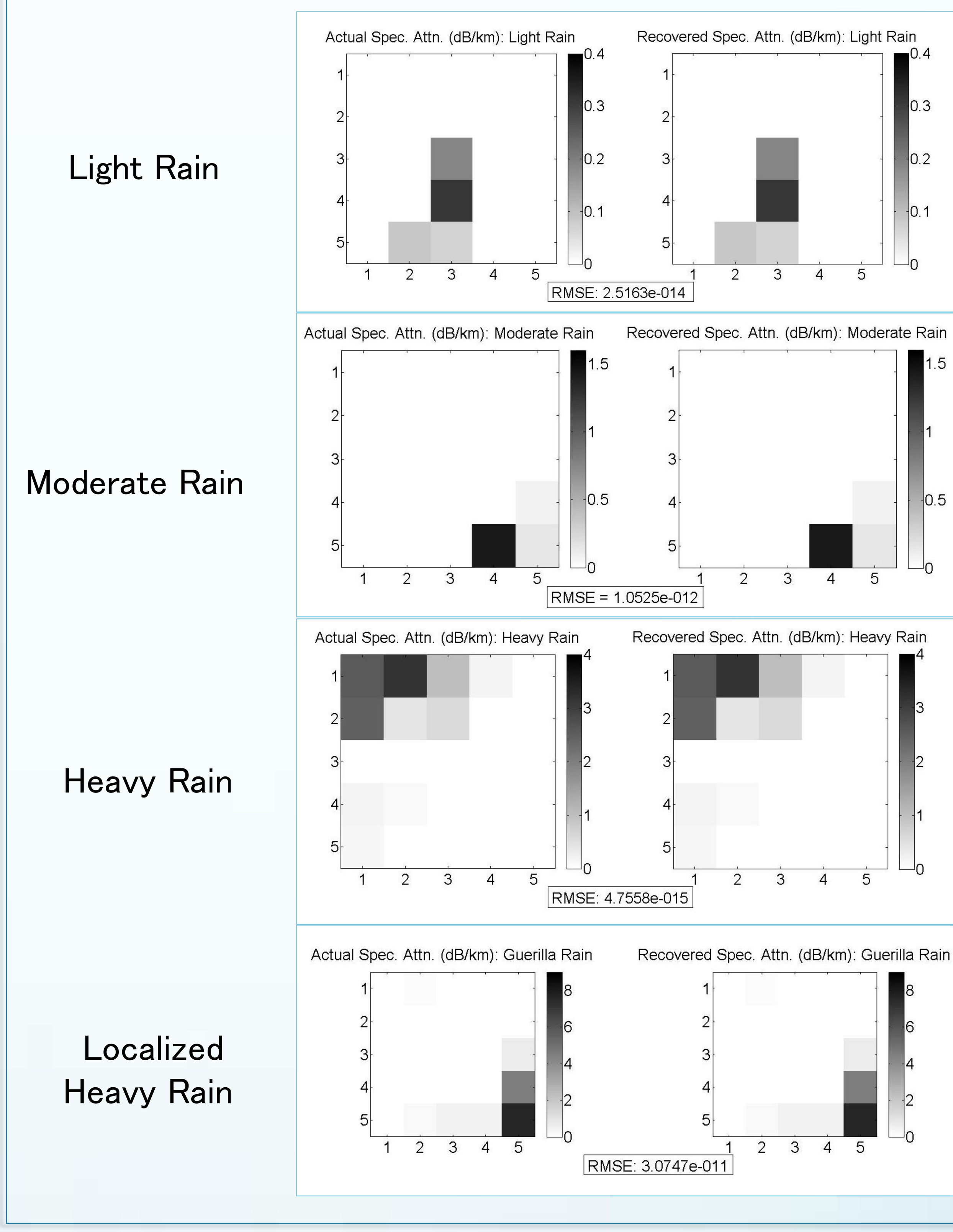
- Errors are small and practically negligible
- Detection of heavy and violent rains are important





Horizontal axis: rainfall at p-th area out of 25-pt areas at time 5q-minute corresponds to index $i=p+25q$

Rainfall Map Reconstructions



Summary

- This research shows the reconstruction of the rainfall field from microwave attenuations using a compressed-sensing based algorithm.
- Proposed method works for all rain intensities, but works better for higher rain rates in smaller areas.
- Useful in the detection of localized heavy rain that can trigger disasters.
- Accuracy is improved when there are more links crossing a single area.
- Urban areas at risk with localized heavy rain will benefit from the proposed method because of the dense microwave networks deployed over them.

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