TARANA WIRELESS, INC.

FOR PUBLIC USE

High Spectral Efficiency Designs and Applications

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Director of Wireless Technology
Opportunity: Un(der)served Broadband

Consumer

3.4B Households Worldwide
Broadband Service Penetration:

- 4% ≥15Mbps (4K ready)
- 20% <15Mbps
- 76% No service

75M U.S.
600M Rest of World

Tarana’s initial addressable markets:

- 2.6B unserved
- 675M underserved consumer HHs
- 115M un(der)served businesses

IoT and Mobile applications come next

Business

150M Commercial Properties Worldwide
Business Broadband over Fiber Penetration:

- 23% Fiber fed
- 77% Copper, coax, or no service

115M underserved businesses
Problem: Current options not addressing demand

- Fiber — High Costs
  - Prohibitive costs
  - Slow deployment
  - Viable only for very short distances

- Wireless — Poor Performance
  - Obstructions
  - Spectrum Scarcity
  - Interference
  - Motion
  - Complex Installation

Viable only for very short distances
**Last-mile wireless: why easier said than done**

**Reality:** Most links have **no** clear line of sight to nearest fiber location (hence, harder to do)

*Sources: Tarana’s tier 1 mobile & fixed operator customers*

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**Last-Mile Link Mix**

- **Line of sight (LoS)**
- **Non line of sight (NLoS)**

80 - 90%
NLoS has several implications

1. Very limited spectrum

- Physics work, but oversubscribed for mobile access
- 3.5GHz (CBRS)
- 5GHz unlicensed, very crowded

2. Multipath

3. Co-Channel Interference

4. Wi-Fi Interference

5. Changing Conditions
Solving NLoS challenges

**Challenge**

- Multipath Fading

**Solution**

- Multipath combining

- Tarana Signal Strength
  - Better 1000x than Others

**Challenge**

- Changing Conditions Installation Challenges

**Solution**

- Continuous, Autonomous Adaptation
  - 5000 times / sec

Unprecedented performance example: Flawless backhaul of LTE cell-on-boat
Solving interference challenges

**Challenge**

Co-Channel Interference for licensed bands

Wi-Fi Interference for unlicensed bands

**Solution**

Perfect Co-Channel Isolation

Precise digital beam- and nullforming

Unlicensed Interference Cancellation

Tarana: Rapid nulling, free channel

Others: Futile channel changes
Putting it all together: Tarana Platform

Revolutionizing Wireless Performance

**10x**

- **NLoS Range**
- **Spectral Efficiency**
- **Interference Immunity**
- **Cell-edge Performance**
- **Stability with Motion**

<table>
<thead>
<tr>
<th>Tarana</th>
<th>Prior State of the Art</th>
</tr>
</thead>
<tbody>
<tr>
<td>10x</td>
<td></td>
</tr>
<tr>
<td>NLoS Range</td>
<td>10x</td>
</tr>
<tr>
<td>Spectral Efficiency</td>
<td>100x fewer cells</td>
</tr>
<tr>
<td>Interference Immunity</td>
<td>100%</td>
</tr>
<tr>
<td>Cell-edge Performance</td>
<td>10x less spectrum</td>
</tr>
<tr>
<td>Stability with Motion</td>
<td>10x free spectrum</td>
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</tbody>
</table>

- Gigabit Fixed Wireless Cells Required per km²
- 1 km
- Spectral Efficiency (sub 6 GHz)
- NLoS bps/Hz/site >10x
- 5 GHz Link Rate with Wi-Fi Interferers
- 100%
- Service Uniformity
- bps/Hz/link
- Fiber-class capacity everywhere
- Link Rate with Moving Obstructions and Reflections
- % of samples over time
- Fiber-class reliability

100x fewer cells
Site flexibility
Fast deployment
Gigabit Residential Broadband Economics

AbsoluteAir 3 Deployment for Typical Neighborhood

Capex $ / HH served

Fiber
Tarana

Share of HH passed

0% 20% 40% 60% 80%

Capex $ / HH served

0 2,500 5,000 7,500 10,000 12,500

Residential Node

3-sector Base Node

trunk to remote node
<table>
<thead>
<tr>
<th>Attribute</th>
<th>AbsoluteAir</th>
<th>4G LTE</th>
<th>Other 5G-NR Massive MIMO</th>
<th>5G mm-wave</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use-Case Focus</td>
<td>Fixed access</td>
<td>Mobile</td>
<td>Mobile</td>
<td>Fixed</td>
</tr>
<tr>
<td>Max Link Speeds</td>
<td>1,600 Mbps</td>
<td>~150 Mbps</td>
<td>&gt; 1,000 Mbps</td>
<td>Gbps</td>
</tr>
<tr>
<td>Edge Link Speed</td>
<td>800 Mbps</td>
<td>&lt; 10 Mbps</td>
<td>&lt; 20 Mbps</td>
<td></td>
</tr>
<tr>
<td>Uniform Service throughout Cell</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>At very short range</td>
</tr>
<tr>
<td>NLoS Range</td>
<td>2-5 km (Gbit)</td>
<td>Few km at low rate</td>
<td>Few km at low rate</td>
<td>100-300m LOS only</td>
</tr>
<tr>
<td>Spectral Efficiency in sub-10 GHz</td>
<td>~70 bps/Hz/site</td>
<td>4-6 bps/Hz/site</td>
<td>~10 to 15 bps/Hz/site</td>
<td>n/a</td>
</tr>
<tr>
<td>spectrum Dense Networks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Availability</td>
<td>2018 - 2019</td>
<td>Now</td>
<td>2020+</td>
<td>2020+</td>
</tr>
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</table>
## Tarana Proprietary Technology Overview

<table>
<thead>
<tr>
<th>Unique Architecture Elements</th>
<th>Performance Benefits</th>
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<tbody>
<tr>
<td>Distributed massive MIMO (DMM)</td>
<td>Large numbers of radios increase precision of all algorithms; even balance between base and remote nodes makes complex techniques feasible</td>
</tr>
<tr>
<td>Precise digital beam- and null-forming on both Tx and Rx</td>
<td>The foundation of all that follows: extremely well-controlled distribution and reception of radio energy only where productive</td>
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<tr>
<td>Closed-loop beamforming adaptation</td>
<td>Collaboration between base and remote nodes further improves digital beamforming accuracy</td>
</tr>
<tr>
<td>3D equalization</td>
<td>Applying signal processing across time, frequency, and spatial domains yields perfect channel even with the most complex diffraction, reflection, and motion effects</td>
</tr>
<tr>
<td>Autonomous, adaptive co-channel interference cancellation</td>
<td>Huge spectral efficiency gains through dense co-channel link operation</td>
</tr>
<tr>
<td>Spatial Multiplexing</td>
<td>Spectrum multiplier (24 streams, per base station site)</td>
</tr>
<tr>
<td>Continuous unlicensed interference cancellation</td>
<td>Yields licensed-class reliability in unlicensed spectrum</td>
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</table>
Field Validation
NLoS Performance

With Tier-1 US carrier

33 Severe NLoS 3.65 GHz links in Manhattan
Nearly all at maximum modulation (256 QAM)
CN at 186 m AGL, single EN mounted on SUV at roof level (locations tested separately)
Links closed autonomously by the time the SUV was parked in each location, without physical re-alignment

% of full rate

<table>
<thead>
<tr>
<th>% of full rate</th>
<th>100</th>
<th>75</th>
<th>50</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>500</td>
<td>1000</td>
<td>2000</td>
<td>2500</td>
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</tbody>
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Long-Distance nLoS

- Application: remote-site connectivity in oil and gas operations in a 20 MHz channel
- Requirements for rapid, low-skilled deployment and high reliability in challenging terrain
- Tests conducted independently by tier 1 global oil producer in Texas field

Example Link:

- 40 Mbps, 54.8km
- 80 Mbps, 41.7km
- 67 Mbps, 34.5km
- 137 Mbps, 15.5km
- 87 Mbps, 11.2km
- CN on 105m Tower

- 40 Mbps (DL+UL), 57.5km
- 40 Mbps, 50.2km
- 86 Mbps, 46.5km
- 85 Mbps, 45.1km
- 143 Mbps, 12.5km

Single PtP CN
Single EN at 2.5m AGL (used in multiple test locations)
Unlicensed link deployment with interference cancellation

- 5.8 GHz 20 MHz link achieving with spectral efficiency of 10 bps/Hz
- End node co-located with Wi-Fi 802.11ac access point and multiple clients on the same UNII-3 channel
Hong Kong Trials (with leading Telco Operator)

**NLoS**
8 fully-obstructed links tested in challenging, dynamic HK environment, with remotes at street level, from 200 to 1,200 m. All closed within 5 minutes of setup, all at high speeds.

**PtMP**
Two 20 MHz co-channel links operated from one CN, in high-density rooftop-to-rooftop setting. Aggregate capacity was very stable and equaled 2x individual link capacity, as expected.

**Interference**
Strong nearby 5 GHz interferer pointed at CN in PtMP configuration. Capacity fluctuated down to 50 Mbps, but returned to maximum rate and full stability with proprietary interference cancellation techniques.

**Over Water**
Tested 3G, 4G, and JDSU traffic over multiple days through 11.6 km link over water (from Victoria to Caritas) — maintained reliable 340 Mbps link (in 40 MHz), weathering tides and monsoon rains.
A wide variety of network applications

<table>
<thead>
<tr>
<th>Application</th>
<th>Economy</th>
<th>Operator Share</th>
<th>User Density</th>
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<tbody>
<tr>
<td>Residential broadband + IoT backhaul</td>
<td>Unique ability to support fixed and mobile wireless applications with the same infrastructure</td>
<td>Both developed- and developing-world ARPU</td>
<td>Low to high</td>
</tr>
<tr>
<td>Smart cities w/ high bandwidth demand</td>
<td>Broad utility of spectrally-efficient, easy-to-deploy, high-capacity links immune to interference, obstructions, and motion</td>
<td>Access to single homes in developed worlds</td>
<td>Rural to dense urban</td>
</tr>
<tr>
<td>Vehicular connectivity</td>
<td>Access to multitenant buildings in developing world, with aggregate ARPU comparable to single developed-world homes</td>
<td>Low to high</td>
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<tr>
<td>Special-purpose networks (marine, security, industrial)</td>
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<td>Enterprise connectivity</td>
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<tr>
<td>Radio Backhaul</td>
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<td>Mobile broadband (next)</td>
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Given unique range and capacity extensions, network economics are very good in either sparse or dense deployments.
Leading a wireless broadband revolution

Let's make it happen together!

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