MVCE Core 5 - Green Radio

Power Efficient Dynamic Resource Scheduling Algorithms for LTE

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Outline

- Introduction to Mobile VCE Green Radio programme
- LTE downlink parameters and channel model
- Joint time and frequency resource scheduling algorithms
- Throughput, fairness and energy efficiency performances of different scheduling algorithms
- Conclusions

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Mobile VCE Core 5: Green Radio

- MVCE based in the UK and runs a program of research sponsored by industry and government with research conducted by Universities
- Green Radio consists of researchers from universities of Bristol, Edinbugh, KCL, Southampton and Swansea steered by industrial sponsors

- Telecommunication industry responsible for substantial CO_2 emission.
- Energy costs increase operational expense (OPEX) for network operators.
- MVCE Green Radio Programme (Core 5): Deliver high data rate services with a 100-fold reduction in power consumption.

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LTE Downlink Transmission

- LTE next major step in mobile radio communications. Aims to reduce delays, improve spectrum flexibility, reduce cost of operators and end users.
- Adopts OFDMA as the downlink access technology.
- Link Adaptation allows choice of MCS to suit channel quality
- Incorporates various MIMO transmission techniques improve system reliability and performance
- Can operate as a ‘closed loop’ system – CSI available at the transmitter

System and Channel Model

Transmission Bandwidth		20 MHz
Time Slot/Sub-frame duration		0.5ms/1ms
Sub-carrier spacing		15kHz
Sampling frequency		30.72MHz (8x3.84MHz)
FFT size		2048
Number of occupied sub-carriers		1201
Number of OFDM symbols per time slot (Short/Long CP)		7/6
CP length (µs/samples)	Short	(4.69/144)x6 (5.21/160)x1
	Long	(16.67/512)
Cell Configuration		Single Cell
Base Station Transmit Power		43 dBm (20W)
Packet Arrival		Full Buffer
Number of users		25
User Velocity		30Km/h

System and Channel Model

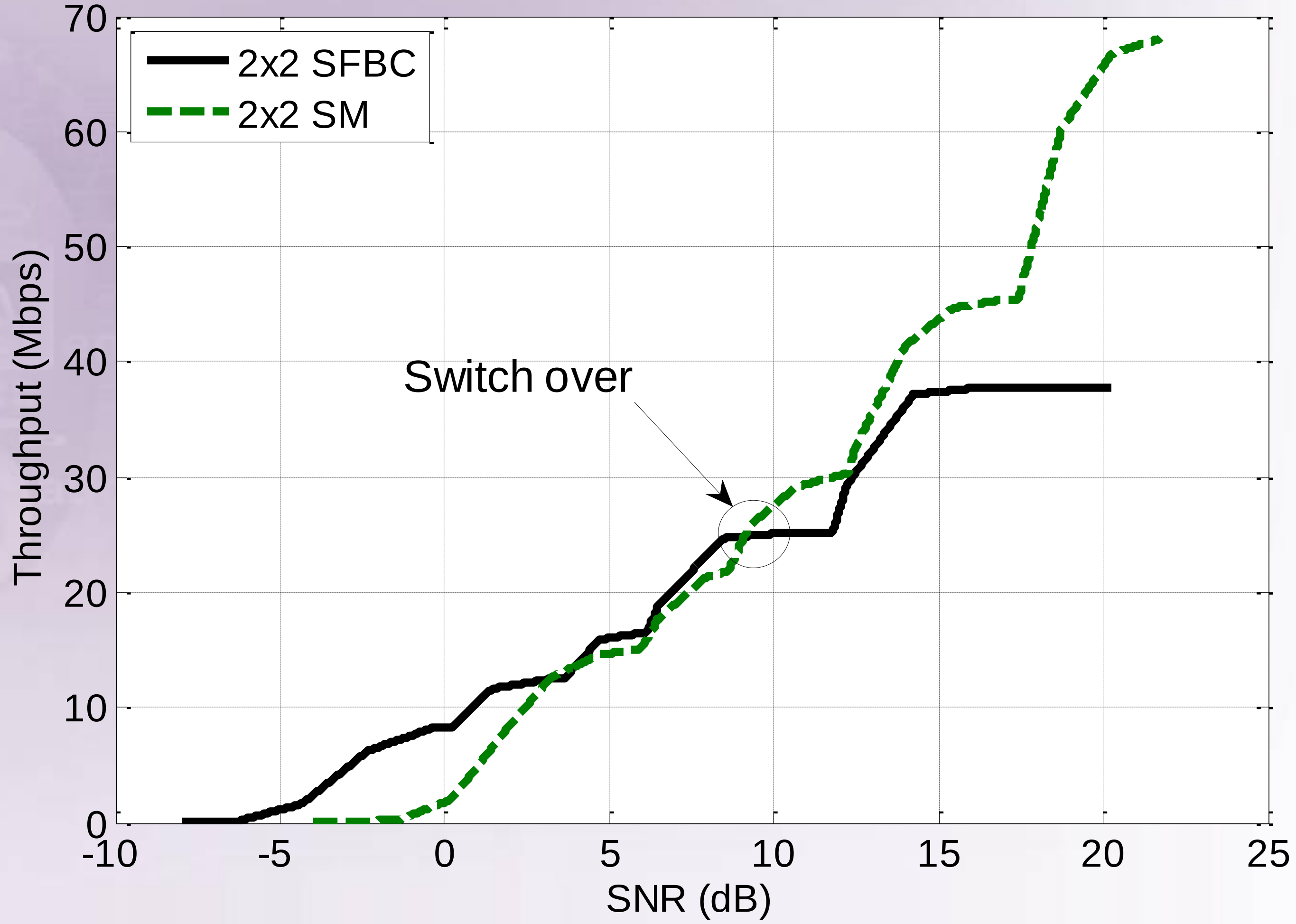
- Spatial Channel Model Extension (SCME) Urban Macro, Cost 231-Hata
- 2x2 MIMO architecture (analysis is readily extendible to higher MIMO orders)
- Low spatially correlated channel for all users
- Error free CQI
- ‘Ideal’ Link Adaptation based on 9 Modulation and Coding Schemes (MCS)

Modulation and Coding Schemes (MCSs)

MCS	Modulation	Cod. Rate	Bit Rate (1x1)	Bit Rate (2x2)
1	QPSK	1/3	10.66 Mbps	20.26 Mbps
2	QPSK	1/2	16 Mbps	30.4 Mbps
4	QPSK	3/4	24 Mbps	45.6 Mbps
3	16 QAM	1/3	21.34 Mbps	40.54 Mbps
5	16 QAM	1/2	32 Mbps	60.8 Mbps
6	16 QAM	3/4	48 Mbps	91.2 Mbps
7	64 QAM	3/5	57.6 Mbps	109.44 Mbps
8	64 QAM	3/4	72 Mbps	136.8 Mbps
9	64 QAM	6/7	82.28 Mbps	156.34 Mbps

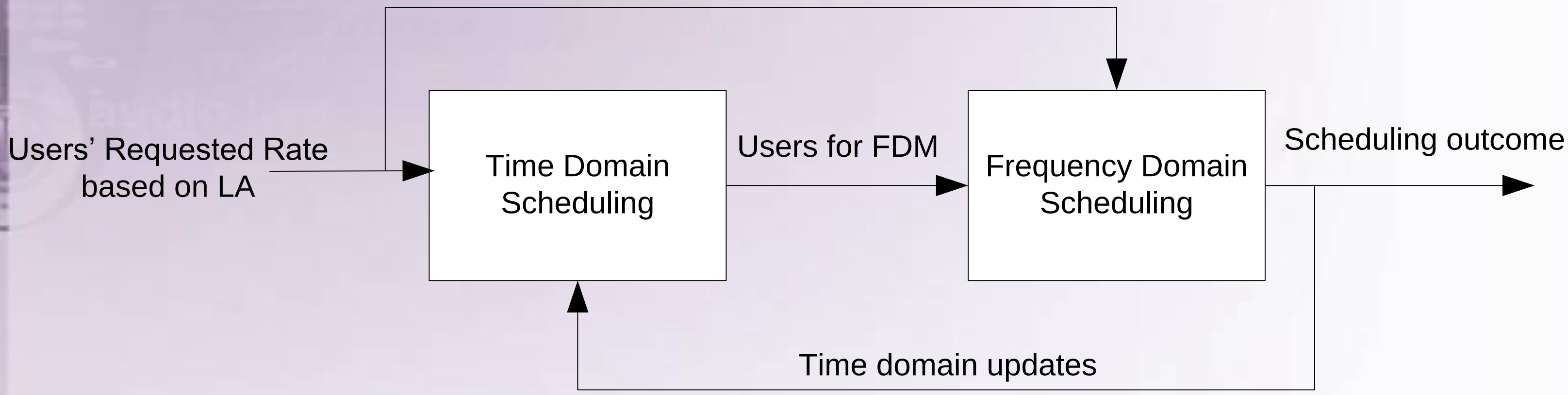
A link adaptation (LA) target of 10% PER is assumed. *Throughput = R(1-PER),* where R and PER are the bit rate and the residual packet error rate for a specific mode respectively

Switching Point for SFBC and SM



Joint time and Frequency Scheduler

- Joint time and frequency RRM strategies
- Time domain scheduler:
  - Initial user pre-selection stage
  - Identify users with relatively good channels whilst maintain an overall fairness for all users.



Time Domain Scheduler (TD)

- **Proportional fair scheduler imposing fairness constraints to users**
  - Strongest users (60%) are selected for the next frequency domain scheduling stage:

$$k^* = \arg\max_k P_k(t) = \arg\max_k R_k(t)/T_k(t)$$

$R_k(t)$: current rate chosen from the set of available MCS

$$T_k(t) = \begin{cases} \left(1 - \frac{1}{t_c}\right) T_k(t-1) + \frac{1}{t_c} R_k(t) & k = k^* \\ \left(1 - \frac{1}{t_c}\right) T_k(t-1) & k \neq k^* \end{cases}$$

$T_k(t)$ user's average throughput over a window in the past. (window length $t_c = 500$)

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Frequency Domain Scheduler (FD)

Frequency domain scheduling strategies for the selected users:

- CSI-independent
  - (1) Round-robin
- CSI-dependent
  - (1) Greedy: maximise rate and power efficiency, least fair
  - (2) Proportional fair algorithm scheme 1 and 2: multi-carrier extension
    - PFA I: scheduler updated after each time interval
    - PFA II: scheduler updated after each PRB
  - (3) Relative strength scheduling algorithm (RSSA)
  - (4) Equal gain dynamic allocation (EGDA)
  - (5) Fair cluster algorithm (FCA)

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Metrics for Performance Measurement

- Throughput
- Throughput fairness measured using Jain's Index
- Power Efficiency is measured by Energy Consumption Rate (ECR) Metric proposed by MVCE Green Radio Programme

$$ECR = \sum_{k=1}^{K} P_k / R_k$$

- Lower ECR indicates higher energy efficiency.
- And a corresponding Power Fairness Index (PFI) derived from the Jain's fairness Index:

$$PFI = \left(\sum_{k=1}^{K} \frac{P_k}{R_k} \right)^2 \Big/ K \sum_{k=1}^{K} \left(\frac{P_k}{R_k} \right)^2$$

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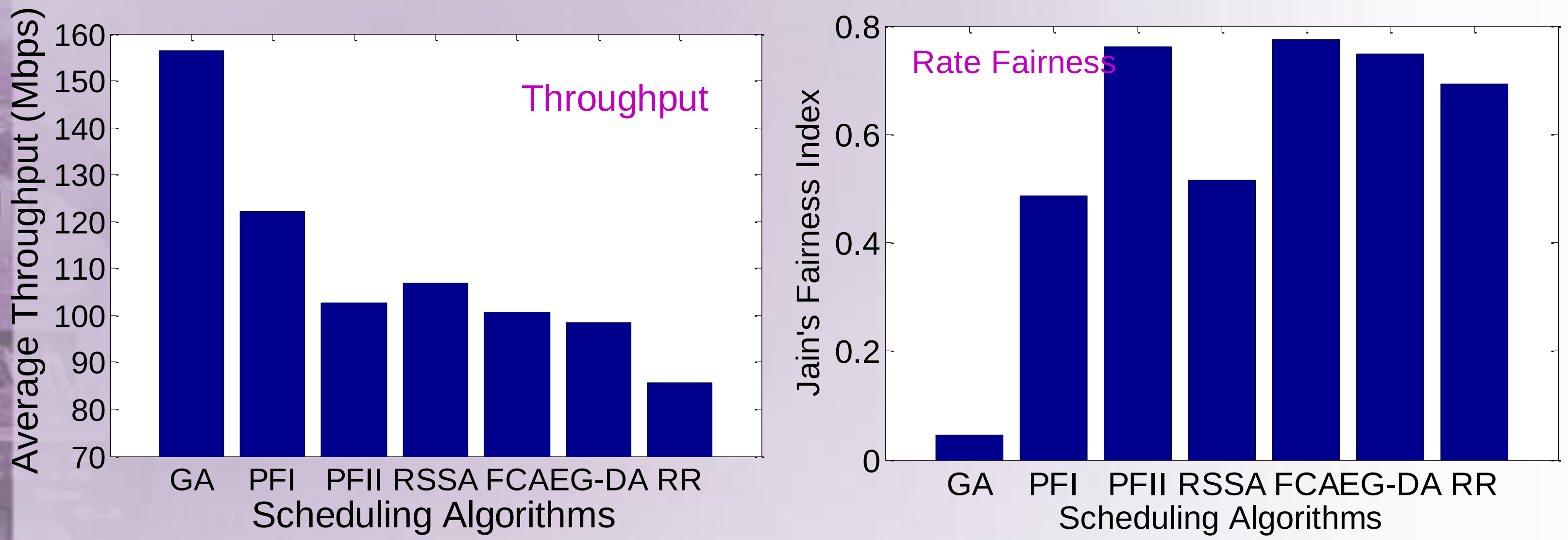
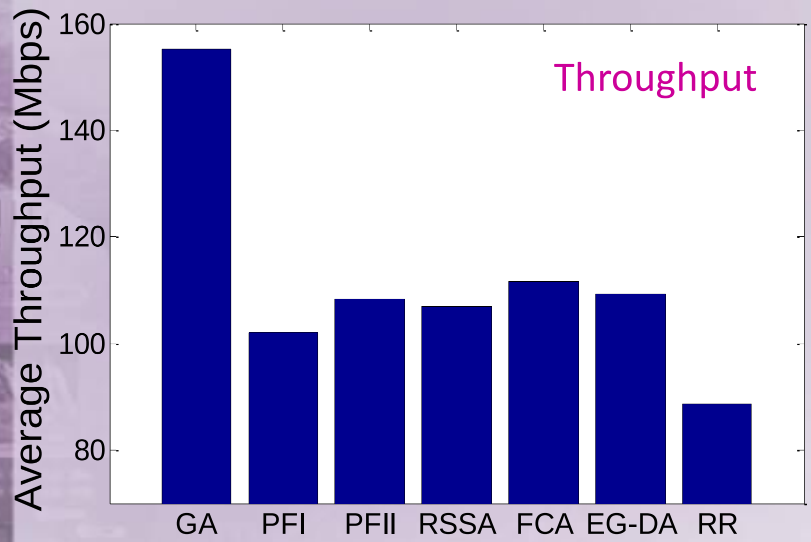
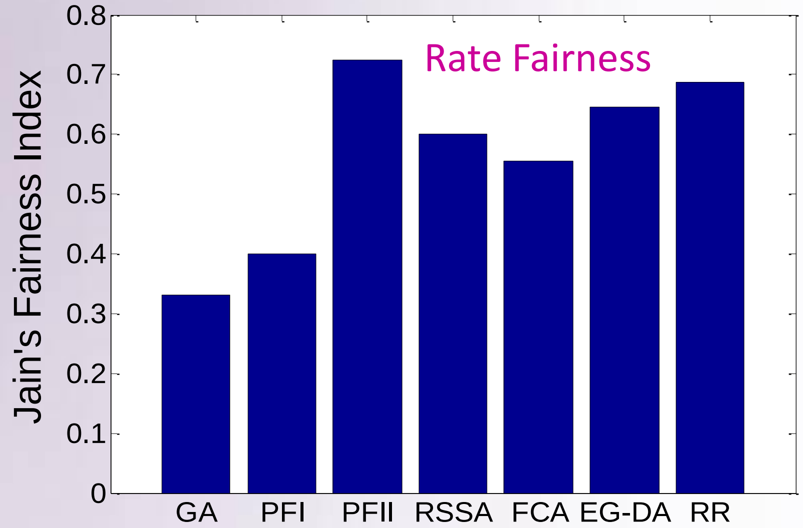
Frequency Domain Scheduler Only



- *All 25 users are allocated resources.*
- *A direct trade-off between throughput and rate fairness.*
- *PF II, FCA, EGDA achieve relatively good performance in terms of both rate fairness and throughput.*
- *PFI and RSSA achieves better throughput but degraded fairness.*

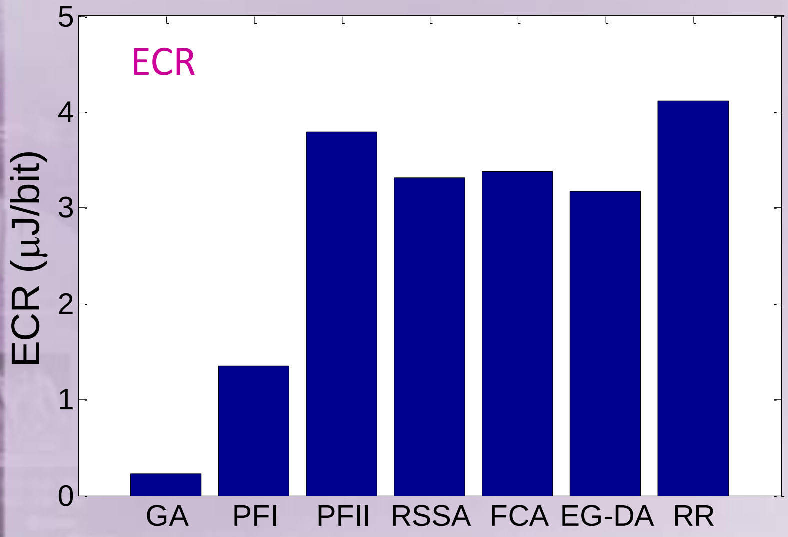
Joint Time and Frequency Domain Scheduler

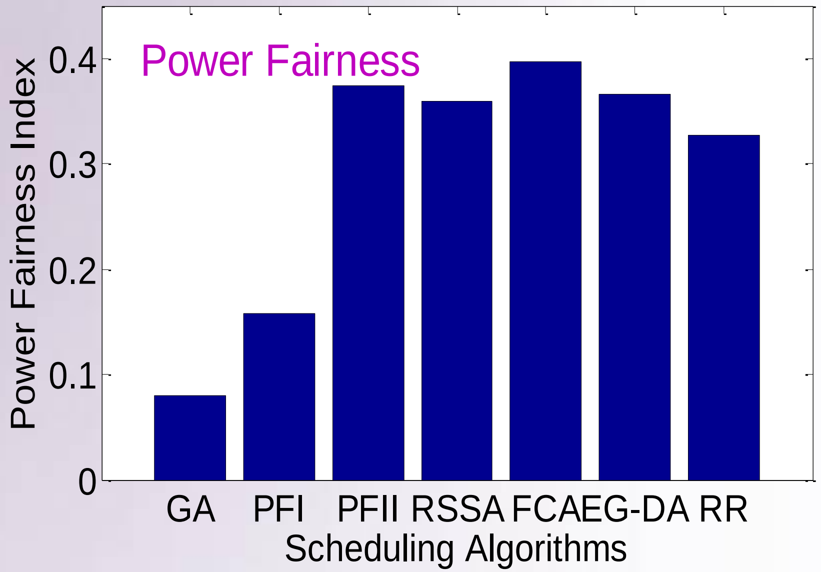




- *60% strongest users are allocated resources.*
- *PFII, FCA and EGDA algorithms achieve 8% increase in throughput.*
- *Improved fairness for GA and RSSA while throughput remains the same.*

Joint Time and Frequency Domain Scheduler

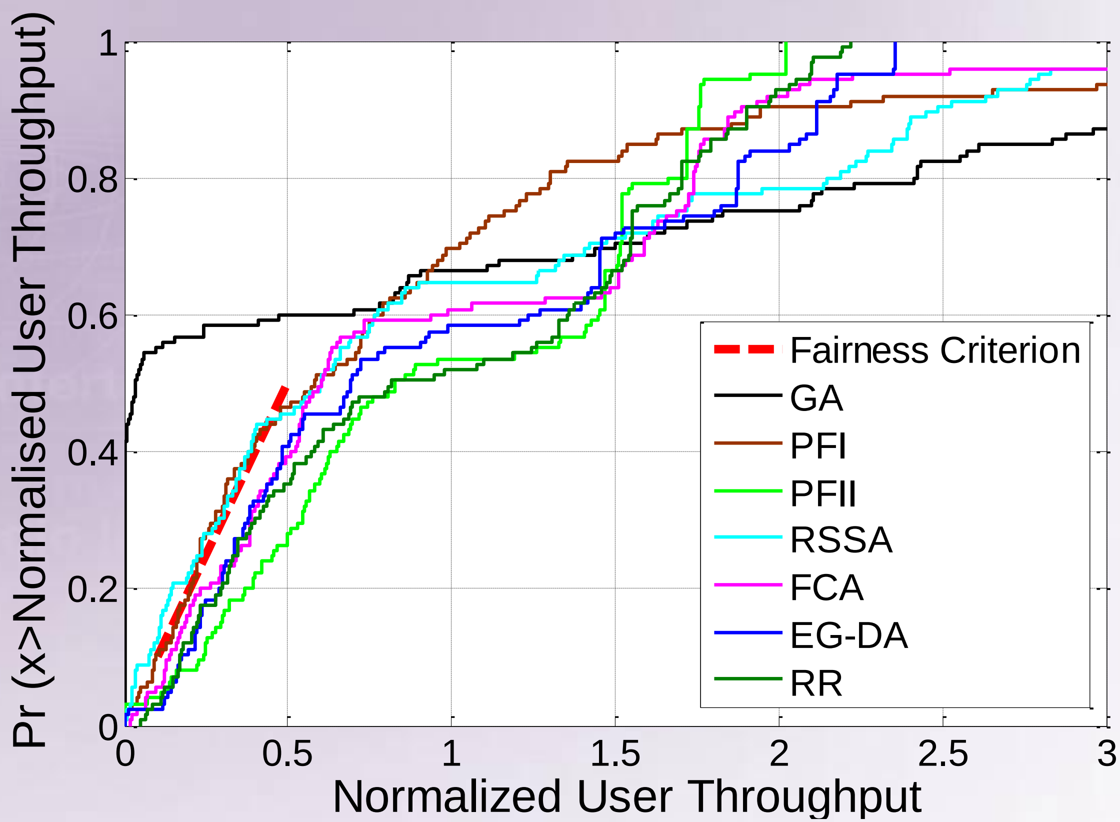




- *GA achieves best throughput, best energy efficiency but poorest rate fairness.*
- *PFA II, RSSA, FCA, EGDA* offers good tradeoff between improving rate fairness, achieving high throughput and power efficiency.

Fairness Performance

Cumulative Distribution Function (CDF) of Normalized User Throughput



- Fairness criteria adopted from [2].
- GA badly fails to meet the throughput bound
- PFA I and RSSA just fail the fairness criteria

[2] 3GPP2 C.R1002-0, "CDMA2000 Evaluation Methodology," Rev.0, 10.12.2004.

…and more recently

- Practical systems don't always operate at full load
- Lower load is an opportunity to save energy
- Need to adapt MIMO, MCS and resource allocation to exploit low load opportunities for energy saving
- Designed a scheduler to do this:
  - Achieves 90% energy saving at 20% load
  - Achieves 80% energy saving at 50% load
  - 50% energy saving across a 'typical' daily load cycle

- **…more on this in future…**

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Conclusions

- Channel-aware scheduling algorithms can achieve significant improvements of both throughput and ECR over a fixed scheduling strategy such as RR.
- Multi-user diversity gain can be translated into energy saving.
- Joint time and frequency domain scheduler achieves better performance than frequency domain only scheduler.
- *PFA*, *FCA*, *RSSA* and *EG-DA* provides a good compromise between throughput and rate fairness, whilst also providing good energy efficiency.
- Lower loads can be exploited to save energy with good link adaptation and resource allocation.

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