Integrated Energy-Directed Test Suite Optimization

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A Background Story

Changing batteries is expensive

Battery supported

Need in situ testing

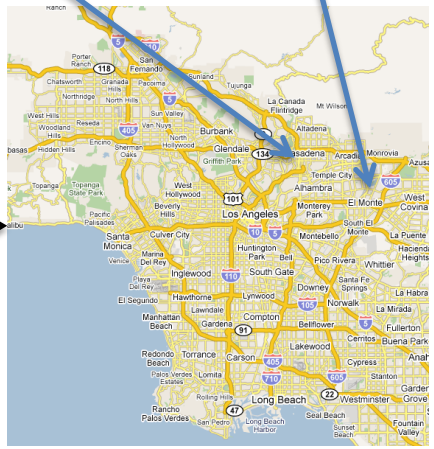
On dams

No stable power supply

In mountains

Alice

Earthquake monitor



LA metro area

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Alice's Problem

- In situ testing is required
  - But it consumes precious battery energy
- Batteries have to be changed frequently
  - But it is difficult to change them

How to reduce the energy usage of an in situ test suite but still maintain the same effectiveness?

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Test Suite Minimization

Coverage	Test Cases t_1	t_2	t_3	t_4	t_5
1. public void updateData(Location prior) {	✓	✓	✓	✓	✓
2. Location current = LocationManager.getLocation();	✓	✓	✓	✓	✓
3. SensorData data = getCurrentData();	✓	✓	✓	✓	✓
4. if (prior.distanceTo(current) > MAX_DISTANCE) {	✓	✓	✓	✓	✓
5. data = Sensors.getData(current);		✓		✓	
6. }	✓	✓	✓	✓	✓
7. if (OutOfDate(data)) {	✓	✓	✓	✓	✓
8. data = Sensors.getData(current)			✓		✓
9. }	✓	✓	✓	✓	✓
10. if (TimePassed() > MAX_TIME) {	✓	✓	✓	✓	✓
11. resendMessage(data);	✓			✓	✓
12. }	✓	✓	✓	✓	✓
13. }	✓	✓	✓	✓	✓
Energy Consumption (mJ)	0.5	0.7	0.2	1.3	1.5

1.4 mJ 2.8 mJ

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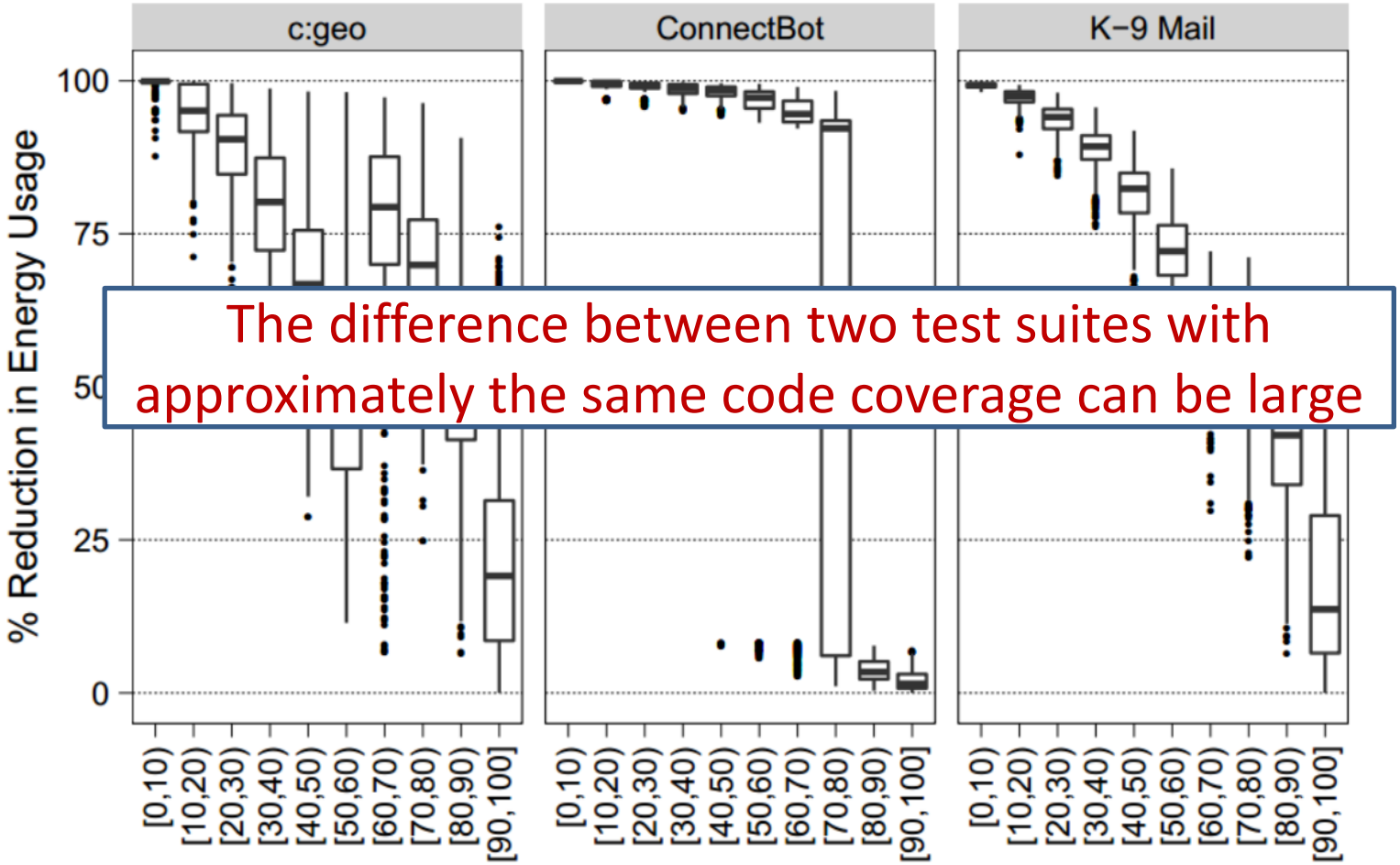
Current Solution

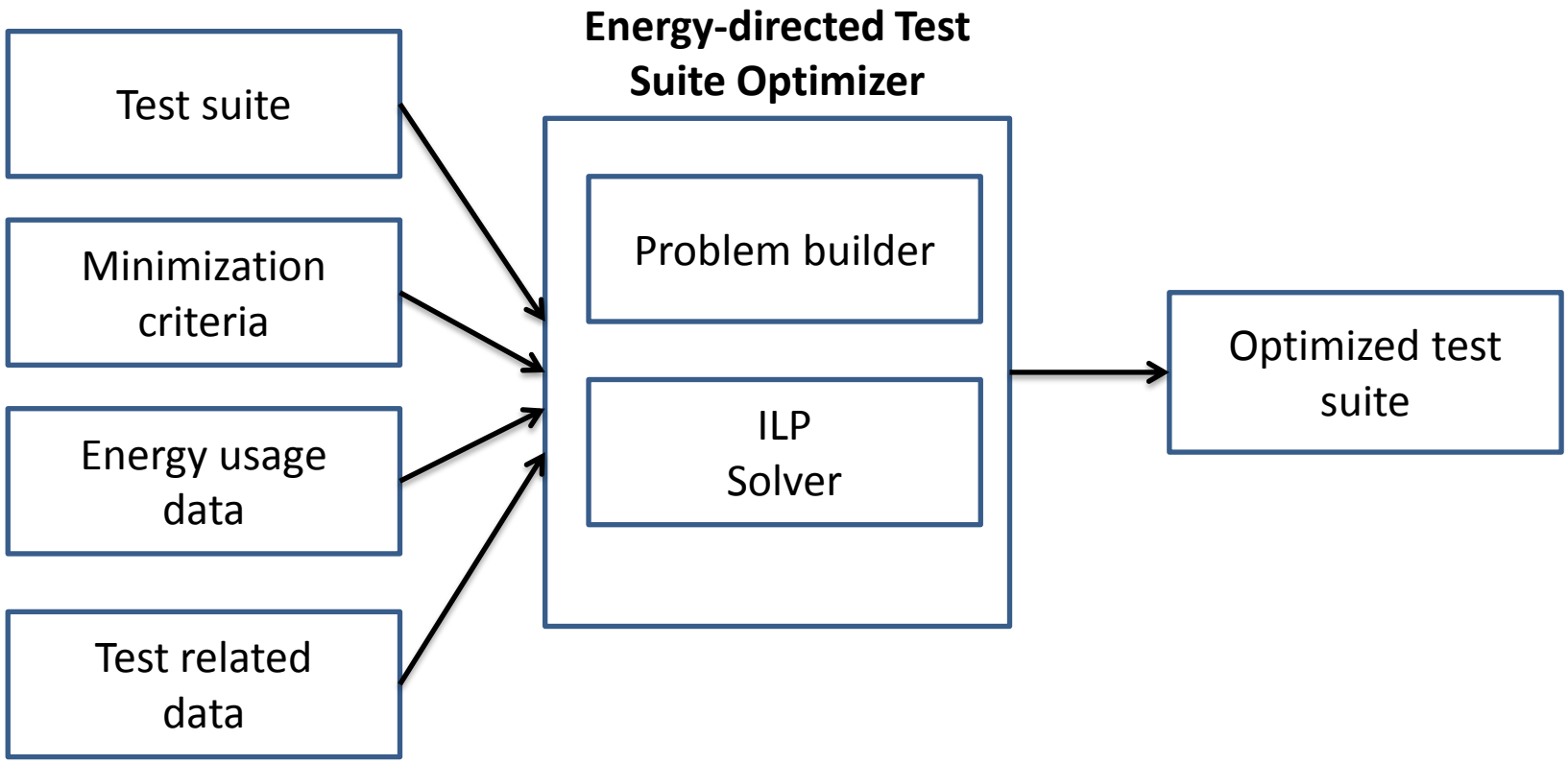
- Energy is not considered [G. Rothermel et al.] [S. Yoo et al.]
  - Optimize the size
  - Optimize the execution time
- These methods may not generate the optimal solution
  - On average, the least energy expensive test suite consumes ≈18 % less energy than the smallest test suite, despite being ≈11 % larger
  - Optimization of time also generates suboptimal solutions with respect to energy

Motivation: Variance in Energy of Test Suites

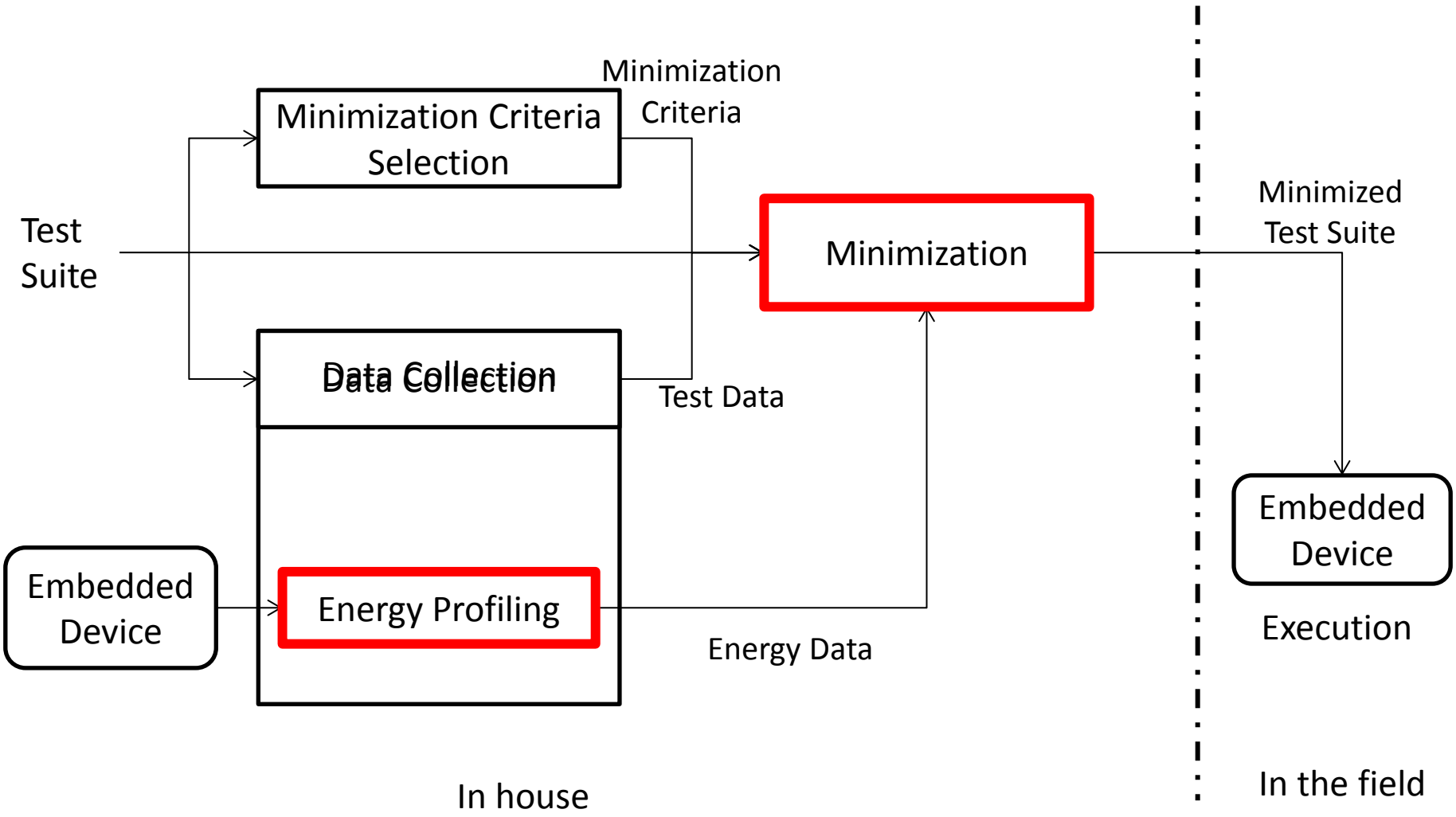


The difference between two test suites with approximately the same code coverage can be large

Our Solution: EDTSO



The Minimization Workflow



EDTSO: Energy Profiling

1. Instrument test cases to collect start and end timestamps
   – Can be fully automated for JUnit or TestNG
2. Execute the test suits on an Energy Measurement Platform (EMP)
   – Many ways to implement EMP [Singh et al.] [Hao et al.]
3. Map the logged time stamps to the energy measurements

EDTSO: Energy Minimization

- Convert the energy minimization problem to an ILP problem [Hsu et al.]
  - Each test case is represented as a binary variable
  - Requirements are represented as constraints
  - Energy is coded as minimization target
  - Generate a set of values of all binary variables that meets all constraints but has minimal energy consumption

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EDTSO: Energy Minimization

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 1. bin: b1, b2, b3, b4, b5;

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10.  s8:           b3 +      b5 >= 1;
11.  s9: b1 + b2 + b3 + b4 + b5 >= 1;
12. s10: b1 + b2 + b3 + b4 + b5 >= 1;
13. s11: b1 +           b4      >= 1;
14. s12: b1 + b2 + b3 + b4 + b5 >= 1;
15. s13: b1 + b2 + b3 + b4 + b5 >= 1;
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Evaluation

- **RQ 1: Effectiveness.** How much energy can EDTSO save?
- **RQ 2: Minimization time.** How much time does EDTSO need?
- **RQ 3: Proxy Measures.** How is EDTSO's performance impacted by using proxy measures?

Evaluation: Protocol

- Hardware platform: LEAP
  - An embedded x86 platform based on an ATOM N550 processo
- Structural
  - Techniqu Larus
- Energy me
  - Connected to the LEAP
  - Profiles the energy consumption at 10 kHz
- Time measurement: instrumented time stamps

Evaluation: Protocol

- To generate more test suites
  - We randomly selected 10,000 subsets of each test suite
  - We grouped the generated subsets into 10 groups based on coverage level wrt original test suite (i.e. 0%-10%, ... 90%-100%)

Evaluation: Benchmarks

Subject	Description	LOC	#Tests
c:geo	Geocaching client	51,451	176
ConnectBot	SSH client	50,581	22
K-9 Mail	Email Client	71,816	38
MobileOrg	Org-mode file manipulation	14,819	87
MyTracks	Track user paths	35,039	310
Sky Map	Astronomical map	21,121	134
Yaaic	IRC client	19,293	28

They are real-world open source apps

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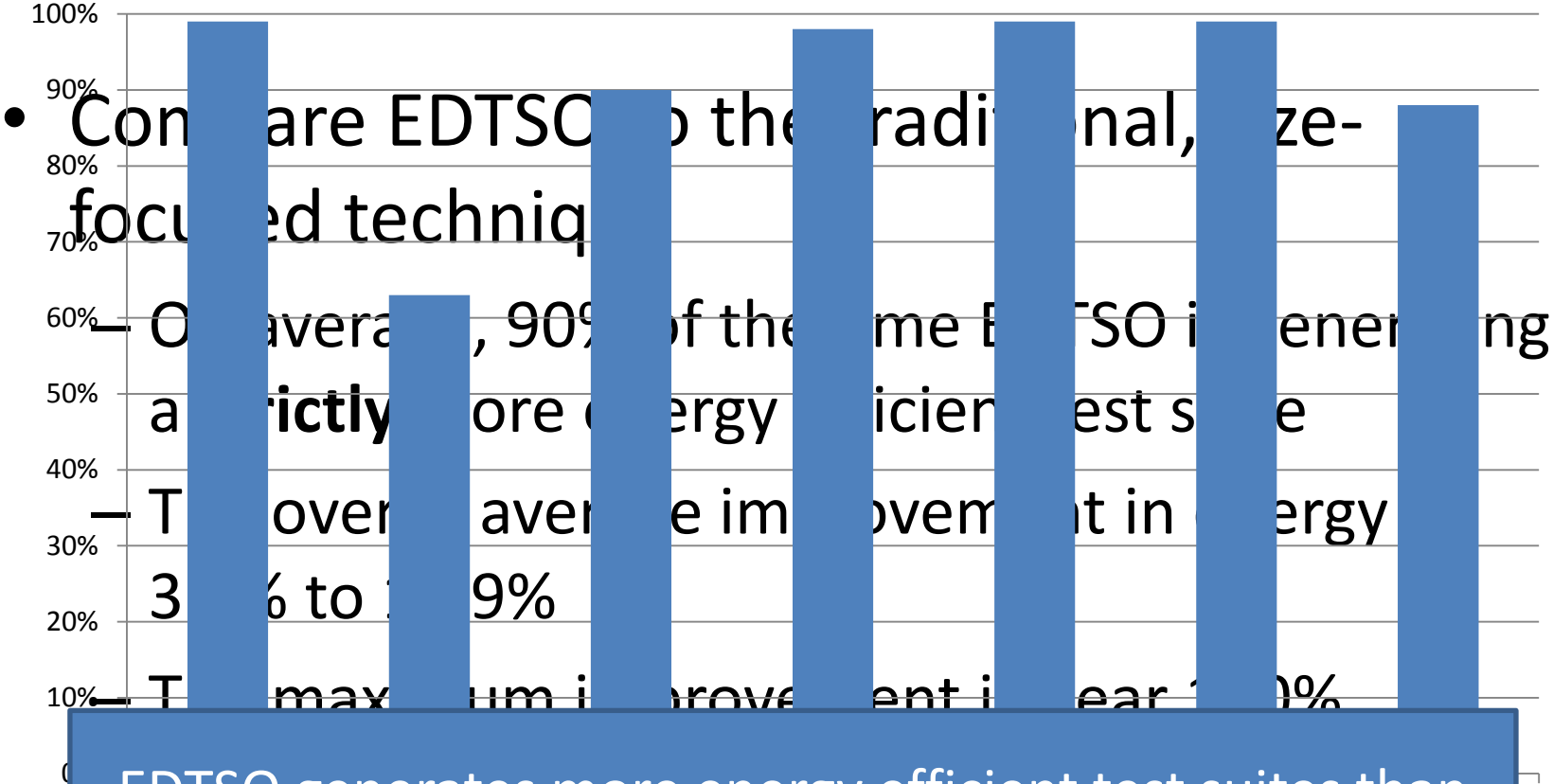
RQ 1: Effectiveness

- Com are EDTSO o the radi nal, ze-focu ed techniq
  - O avera , 90% f the me E TSO i ener ng a rictly ore ergy icien est s e
  - T over aver e im ovem t in ergy 3 % to 9%
  - T max um i rove ent i ear 0%



EDTSO generates more energy efficient test suites than size-focused approaches

Frequency of EDTSO generating a more energy efficient test suite than traditional size focused approach

RQ 2: Minimization Time

- We measure the absolute time of EDTSO
  - All 70,000 generated subsets are minimized in less than 1 second
- We compare the minimization time of EDTSO to traditional size-focused approach
  - Only Yaaic has a significant difference ($p > 0.05$)

There is no significant difference in terms of minimization time

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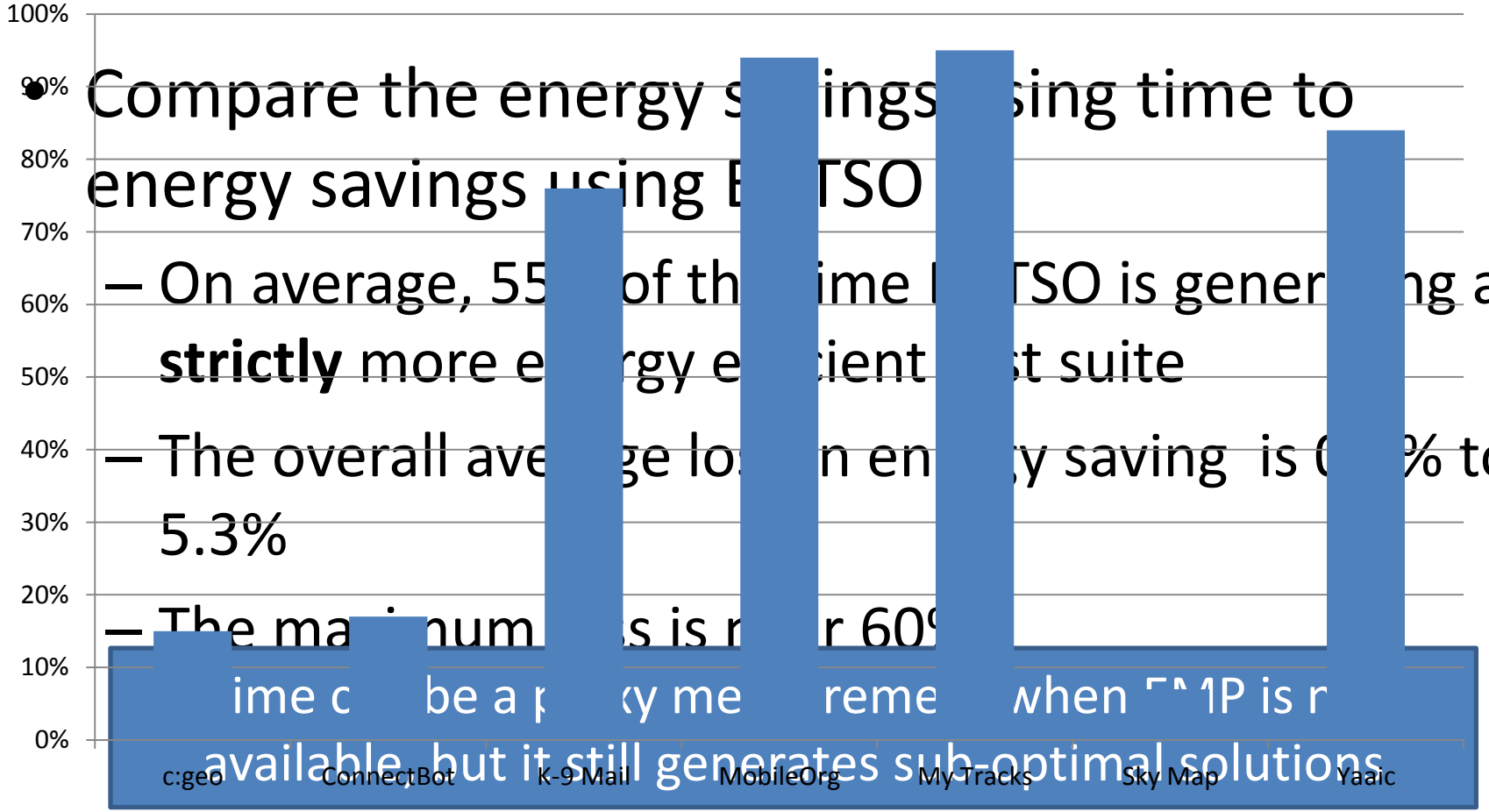
RQ 3: Proxy Measurement



- Compare the energy s ings sing time to energy savings using E TSO
  - On average, 55 of th ime l TSO is gener ng a **strictly** more e rgy e cient st suite
  - The overall ave ge lo n en y saving is 0 % to 5.3%
  - The ma imum s is r r 60
- ime c be a p y me reme when EDTSP is r available, but it still generates sub-optimal solutions

Frequency of EDTSO generating a more energy efficient test suite than using time as a proxy measurement `

Conclusion

- EDTSO minimizes the energy of in situ test suites
- EDTSO can be integrated into current test suite minimization workflows
- We evaluated EDTSO on realistic market apps
  - Saved up to 95% energy compared to traditional size focused approach
  - Using time as a proxy measurement may lose up to 60% of energy savings
  - EDTSO was as fast as traditional approaches

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